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TESTING OF
THE WCSS RAILBUS ON THE
INCO RAILWAY LINE

BY

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17. Abstract

The Winnipeg Coach Sales and Service (WCSS) prototype railbus was tested on the Inco Pipe Mine railway line in Thompson, Manitoba. During the course of the tests, 3347 km of operation were accumulated. Tests carried out evaluated stability, curving, switching, braking and operation of the various auxiliary systems including the turntable. The tests were generally successful and the vehicle proved to be capable of sustained safe speeds of up to 90 km/h. Vehicle ride was judged to be "just satisfactory" on the British Rail Ridemeter scale. Wheel and bearing life was judged to be satisfactory for demonstration operation. Interior noise was a problem and was reduced from 93 dB(A) to 87 dB(A) by various modifications. The one major hardware failure in the program was the turntable, which required strengthening and rework after 50 cycles of operation.

In general, the rail-related modifications were successful. The vehicle proved to be unreliable, however, largely as a result of its age and modification history. Recommendations are made for improvements to increase reliability.

CN and CTC approval was gained for non-passenger operation on the Thompson-Pikwitonei-Thicket Portage railway line.

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17. Résumé

Ce rapport rend compte des essais en service du railbus réalisé par la Winnipeg Coach Sales and Service Ltd sur le tronçon de chemin de fer appartenant à la Inco Pipe Mine à Thompson (Manitoba). Ces essais, durant lesquels le railbus a parcouru un total de 3 347 km, avaient pour but d'évaluer sa stabilité, ses caractéristiques d'inscription dans les courbes, ses passages sur les aiguillages et ses performances en freinage, ainsi que le fonctionnement de ses appareils auxiliaires, y compris la table tournante. Le railbus a passé ces tests avec succès et s'est montré capable de soutenir en toute sécurité des vitesses pouvant atteindre 90 km/h. Sur le plan confort de roulement, le matériel n'a pas fait mieux que "juste satisfaisant" suivant l'échelle de confort établie par la British Rail. La durée de vie des roues et des paliers a été jugée suffisante pour les besoins du programme d'essais. Le niveau sonore à l'intérieur du véhicule a été jugé trop élevé; il a donc été ramené de 93 à 87 dB(A) par diverses modifications. Le seul problème majeur a été la panne de la table tournante qui a dû être renforcée et modifiée après 50 cycles de fonctionnement.

Les modifications visant à adapter le bus à la circulation ferroviaire ont été généralement réussies. Par contre, la fiabilité générale du véhicule a été faible, attribuable à son âge et à ses antécédents. Des recommendations sont formulées dans le but de relever la fiabilité générale du véhicule. Tant le CN que la CTC ont donné leur approbation pour une exploitation sans passagers sur la desserte Thompson, Pikwitonei, Thicket Portage.

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SUMMARY

Winnipeg Coach Sales and Service (WCSS) Ltd. converted a Western Flyer bus owned by Transport Canada into a test railbus for operation on railway tracks. The vehicle was used to evaluate railbus design concepts, address institutional and regulatory issues, and assist in evaluating the feasibility of railbus operations in remote northern communities. Preliminary tests carried out on the Greater Winnipeg Water District Railway in Manitoba showed that the concept was workable; however, further development testing was required.

The work reported herein describes an exhaustive series of tests carried out over a period of three months on the INCO rail line in Thompson, Manitoba. The tests had the major objectives of accumulating 3,000 km of operational experience; gaining acceptance from the Canadian Transportation Commission (CTC) and Canadian National Railways (CN) for non-passenger-carrying test operation on the CN line between Thompson, Thicket-Portage, and Pikwitonei; and, establishing the maximum safe operating speed on both tangent and curved track.

The work carried out followed a logical sequence: vehicle inspection, engineering assessment of various technical features of the vehicle, vehicle improvements designed to address known deficiencies of the design, vehicle testing along with modification and retesting where necessary, and, finally, analysis of test results.

The main tasks performed during vehicle preparation were the inspection of safety-related components such as wheel bearings and brakes, rectification of wheel lateral run-out and remachining of each wheel to a standard AAR 1-in-20 profile. One feature that proved objectionable at the driver's location was engine noise, which was corrected by installing an acoustic absorbing pad to the engine cover. In addition to the above work, some equipment required to meet CTC regulations, such as classification lights, was installed.

The tests were carried out on the INCO "Pipe Mine" rail line, which is constructed of 115-lb rail using 39-foot staggered joints. Test sections were selected with curves, switches, and tangent track that are representative of northern operation.

The tests showed that:

- Vehicle interior noise was reduced to an acceptable level of 87 dB(A) by the added insulation;
- Lateral and vertical accelerations of the axles averaged 0.5 G and 0.9 G respectively, with peaks of 4.2 G and 1.5 G respectively at 72 km/h;
- Ride quality was judged to be "just satisfactory", with an average British Rail Ridemeter Index of between 3.0 and 3.8 at 72 km/h;

SUMMARY (Cont'd)

- The vehicle was determined to be safe and demonstrated no derailing tendencies to a maximum test speed of 90 km/h;
- Fuel consumption averaged 5.43 km/l (15 mpg), 18.83 l/100 km;
- Reliability of wheels and wheel bearings was very satisfactory;
- The turntable proved to be unreliable, with one major failure resulting in major rework and repositioning of the unit under the centre of gravity of the railbus;
- Battery life was sufficient for 24 hrs of operation of emergency systems, but the auxiliary heater output was insufficient;
- The drawbar operated well in push and pull tests;
- The Deadman feature operated, but required some improvements; and
- The emergency engine shut-off required improvements.

Overall, an accumulation of 3347 km of test operation was recorded, with the resultant conclusion that the "rail" features of the vehicle functioned very successfully and the braking, stability, curving, and switch behaviour was acceptable. The main causes of any unreliability were a result of the age and prior inherent difficulties with the bus, such as starting, contamination of fuel filters and tank, and minor electrical faults. The single major failure was the turntable.

In summary, it is concluded that the vehicle is suitable as a non-revenue-passenger-carrying vehicle for controlled demonstration purposes in remote northern service. A number of reliability issues need to be further addressed in the planned winter test programme.

SOMMAIRE

Ce rapport rend compte des essais en service du "railbus", un autobus de type Flyer appartenant à Transports Canada et que la Winnipeg Coach Sales and Services Ltd. (WCSS) a converti en véhicule ferroviaire. Le but de ces essais était d'évaluer le concept retenu, de vérifier la conformité du véhicule aux règlements et de déterminer son aptitude à desservir les régions septentrionales isolées. Les essais préliminaries effectués dans la région de Winnipeg (Manitoba) ont montré que le concept général était bon, mais que des essais de mise au point étaient nécessaires.

Le rapport décrit la batterie d'essais d'une durée de trois mois faits sur la ligne de chemin de fer appartenant à la INCO à Thompson (Manitoba), et dont les objectifs étaient les suivants: parcourir au moins 3000 km; obtenir l'autorisation de la CCT et l'aval du CN pour une exploitation expérimentale sans passagers sur la voie du CN entre Thompson, Thicket-Portage et Pikwitonei; déterminer la vitesse maximale de sécurité en courbe et en alignement.

Les trauvaux ont été ordonnés logiquement: inspection générale, évaluation des caractéristiques mécaniques, modifications visant à corriger certaines lacunes de base, essais en service suivis des mises au point et confirmation par d'autres essais et, enfin, étude des résultats des essais.

La principale tâche lors de la préparation du véhicule a été de vérifier les organes importants du point de vue sécurité, comme les paliers des roues et le système de freinage, d'éliminer le défaut d'alignement des roues et de donner à celles-ci un profil normalisé AAR de 1 sur 20. Une caractéristique défavorable du point de vue du conducteur a été le niveau sonore du moteur, lequel a été atténué par une isolation acoustique améliorée du capot. En outre, il a fallu installer des feux de signalisation afin de respecter la réglementation de la CCT.

La ligne de sur laquelle les essais ont été conduits, de la INCO, est faite de rails 115 lb à joints décalée de 30 pieds, les tronçons choisis comportant un ensemble de courbes, d'aiguillages et d'alignements caractéristiques.

- Le niveau sonore à l'intérieur a été ramené au niveau acceptable de 87 dB (A) par une meilleure isolation acoustique.

- Les valeurs moyennes d'accélération transversale et verticale des essieux ont été de 0,5 et 0,9 g, respectivement, les valeurs maximales enregistrées ayant été de 4,2 et 1,5 g, à la vitesse de 72 km/h.

- Sur le plan confort de roulement, le matériel a été jugé "juste satisfaisant", ayant enregistré un indice entre 3 et 3,8 à 72 km/h suivant l'échelle de confort établie par la British Rail.

- Le matériel a soutenu en toute sécurité sa vitesse d'essai maximum de 90 km/h.

SOMMAIRE (Cont'd)

- La consommation a été de 18,83 l aux 100 km (15 milles/gallon), en moyenne.
- La fiabilité des roues et des paliers a été jugée très satisfaisante.
- La table tournante est tombée en panne et il a fallu la déplacer pour la faire coincider avec le centre de gravité du véhicule.
- La charge de la batterie a été suffisante pour faire fonctionner les systémes d'urgence pendant 24 h; par contre, le rendement du système de chauffage d'appoint a été insuffisant.
- La barre d'attelage s'est bien comportée aux essais de traction et de poussée.
- Le dispositif de sécurité dit de l'"homme mort" a fonctionné, mais il nécessite une mise au point.
- Même choise pour le dispostif d'arrêt d'urgence du moteur.

Dans l'ensemble, après avoir parcouru 3 347 km, le matériel a obtenu une très bonne cote pour ce qui concerne ses organes de roulement "ferroviaires" et a montré un comportement acceptable du point de vue du freinage, de la stabilité de marche, de l'inscription dans les courbes et du passage sur les aiguillages. Quant aux points faibles constatés, ils résultant de l'âge du matériel, de certains défauts de bsae, comme la difficulté aux démarrages, la contamination des filtres de combustible et du réservoir et certaines faiblesses du circuit électrique. Le seul problème majeur a été la panne de la table tournante.

En définitive, le matériel convient au transport de passagers non payants dans des conditions contrôlées comme celles du projet pilote de desserte des régions septentrionales isolées. Certains problèmes de fiabilité encore à résoudre devront être inclus dans le programme d'essai hivernal en voie de préparation.

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1.0 INTRODUCTION

1.1 BACKGROUND

A Western Flyer bus has been converted for operation on railway tracks by Winnipeg Coach Sales and Service (WCSS) Ltd. This vehicle (Figure 1) is intended to serve as a test vehicle for evaluation of related engineering design concepts, addressing institutional and regulatory issues, and assessment of the overall feasibility of railbus operations in northern remote communities. A demonstration passenger service is planned for northern Manitoba in the winter of 1985-1986, linking Thicket Portage and Pikwitonei with the City of Thompson.

Preliminary vehicle operational tests had previously been conducted by WCSS on the tracks of the Greater Winnipeg Water District Railway in Winnipeg, Manitoba. The results have been described in reports prepared by WCSS and Dynamic Sciences Limited (DSL) previously published by Transport Canada (Ref. 1 and 2). These preliminary tests indicated that the conversion was workable but that the vehicle was likely to be sensitive to track inputs, particularly from the staggered rail joints at 39 foot intervals common on remote service lines.

The work reported herein involved the next stage of development testing during which the railbus was significantly modified and underwent a series of intensive operational trials on railway lines owned by INCO Limited in Thompson, Manitoba. The performance and reliability of the vehicle was closely monitored during these trials in order to assess its design and operating performance in consideration of the objectives for vehicle use.

The planning phase of these operational trials was reported in a preceding TDC report prepared by TTL (Ref. 3). The tests were undertaken on the INCO line due to its accessibility for test purposes, no other traffic to cause interference, and the continuing support of the program by INCO.

The Transportation Development Centre (TDC) has been closely involved with the project since its inception and contracted with WCS for the earlier program during which the vehicle conversion to rail operation was carried out. Transport Canada subsequently purchased the railbus from WCSS.

1.2 OBJECTIVES

The Railbus Development and Demonstration Programme is being undertaken by TDC under a testing agreement with the Rail Passenger Directorate (DGRP) of the Transport Canada Surface Administration.

The overall objective is to develop and demonstrate a technology suitable for rail services to remote communities where conventional rail service is extremely costly and alternative

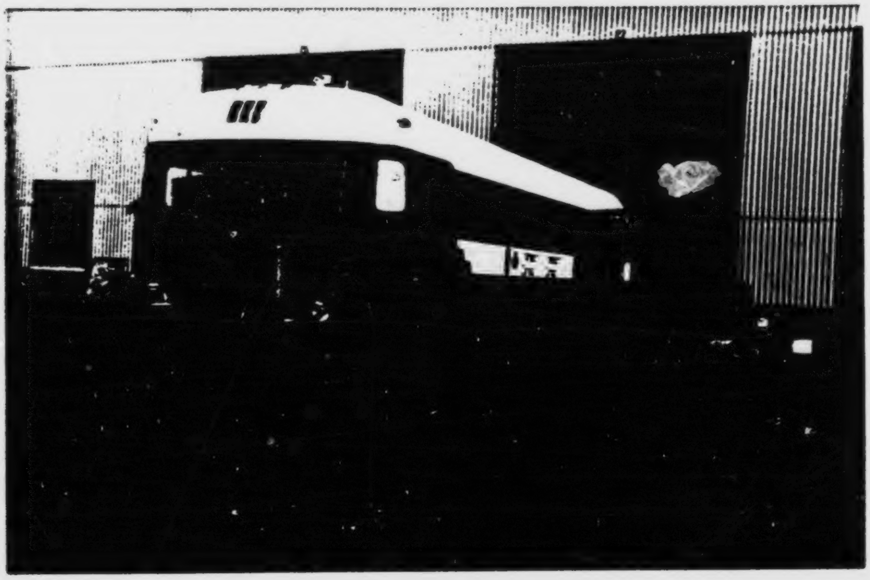


FIGURE 1: THE WINNIPEG COACH SALES AND SERVICE RAILBUS BASED ON A WESTERN FLYER BUS DESIGN

modes of transportation are not available. One element of this programme involves the testing and evaluation of the WCSS vehicle.

The specific objectives for the testing phase of the WCSS vehicle that is the subject of this report of the program were to:

a) Accumulate 3000 km of operational experience;
b) Gain acceptance by CN Rail and by the Canadian Transportation Commission (CTC) that the railbus vehicle is acceptable for operation in non-passenger carrying service on the Thompson-Pikwitonei-Thicket Portage line of CN Rail and
c) Establish the maximum safe operating speed on both tangent and curved track.

This testing program had two other underlying objectives, namely to establish what effect increasing mileage would have on the vehicle and determine its suitability for winter operation. These objectives were addressed herein.

The vehicle modifications and improvements required prior to putting the bus into actual passenger demonstration/operation are further described in this report. The results of the testing, conclusions and recommendations form the main body of the report.

1.3 METHODOLOGY

The methodology followed for the work consisted of a logical sequence outlined below in point form:

- Vehicle inspection;
- Engineering assessment;
- Vehicle improvements and preparation;
- Vehicle testing;
- Vehicle modifications;
- Vehicle retest; and
- Analysis of results.

In parallel to the stream of engineering and test activities documentation for an application to the CTC for permission to operate on the specified Thompson-Thicket Portage-Pikwitonei railway line was prepared and submitted to TDC.

The vehicle inspection was carried out at the INCO site by TTL engineering personnel and consisted of a review of available documentation as well as the generation of a physical and photographic record of the vehicle status. The photographic record of the vehicle and testing is included in this report as Apendix 1. The engineering assessment consisted of theoretical calculation and analysis of such parameters as expected bearing life as well as a comparison of the vehicle with the known requirements of the CN and CTC.

Vehicle improvements were carried out to rectify known deficiencies from previous testing, incorporate changes suggested by the engineering assessment, and carry out specific vehicle changes required by the CN and CTC. This work was followed by intensive vehicle testing for over 3,000 km on the INCO railway line including trials of stability and curving. Some tests, particularly those of the turntable, resulted in the requirement for vehicle modifications before the tests could be completed. These modifications were carried out at the INCO and WCSS workshops in Thompson and Winnipeg, respectively. The program concluded with retest of the modified features and analysis of the test results.

1.4 ORGANIZATION OF THE REPORT

The organization of the report follows the above outlined methodology closely. Section 2.0 reviews the vehicle inspection and assessment, and Section 3.0 the operational preparation work required to carry out the program. The preparation of the vehicle itself is described in Section 4.0 and modifications carried out at mid-program and described in Section 5.0. The test program is summarized in Section 6.0 and reported in greater detail in Appendix 2. The operational tasks, including planning for running on the CN line and the CTC application, are reported in Sections 7.0 and 8.0, respectively.

Section 9.0 of the report summarizes the conclusions of the work and the formulated recommendations of the work carried out.

2.0 VEHICLE ENGINEERING ASSESSMENT

2.1 VEHICLE INSPECTION

The vehicle was inspected for wear, fatigue, strength and adequacy of design and, where required, recommendations made for further modifications.

2.1.1 Wheel Bearings

Measurements and photographs were taken of the front left-hand axle/wheel bearing assembly. The wheel bearings were removed, inspected and the wheel reassembled to assure adequate running clearance characteristics (Figure 2). Observations indicated that there was no evidence of bearing wear, excessive wheel play, nor brinelling of surfaces on any of the wheel bearing surfaces (four wheel assemblies). Standard bearing grease was used to repack the wheel assemblies.

A preliminary analysis of worst case bearing life resulted in a value of 1,066 hours for the inner hub bearing when using the maximum vehicle load configuration of 12,045 kg (26,500 lb), average vehicle service speed of 60 kph and a lateral wheel loading (curving) of 1 G. Track inputs of 10 G on the wheel were assumed in the analysis. The estimates made for axle and bearing load calculations are discussed further in Section 6.0.

2.1.2 Wheels

The rail wheel design, its method of attachment and running surfaces were inspected for fatigue and wear. All welded surfaces were cleaned and magnafluxed for crack observations. Wheel surfaces, including the flange, were measured to be non-concentric with a maximum vertical runout of 1.4 mm and a highest lateral runout of 3.3 mm on the front LH wheel assembly. Wheel profiles were taken and surfaces found to have several flat spots (from slide-braking) and some had excessive wear grooves - particularly the front left wheel, as a result of previous use on freight wagons.

Through discussions with suppliers and manufacturers, and a review of previous tests it was concluded that the design was adequate for the vehicle weight and duty described. Continued monitoring of the wheels and attachments was carried out during the test program.

2.1.3 Suspension

Vehicle suspension elements were observed for soundness and measurements taken of general characteristics (Figure 3). Suspension travel prior to hard-metal bottoming was measured at nearly 60 mm for both front and rear axle - rubber stops were non-existent at the front and rear axle assemblies. A recommendation was made for the later addition and/or relocation

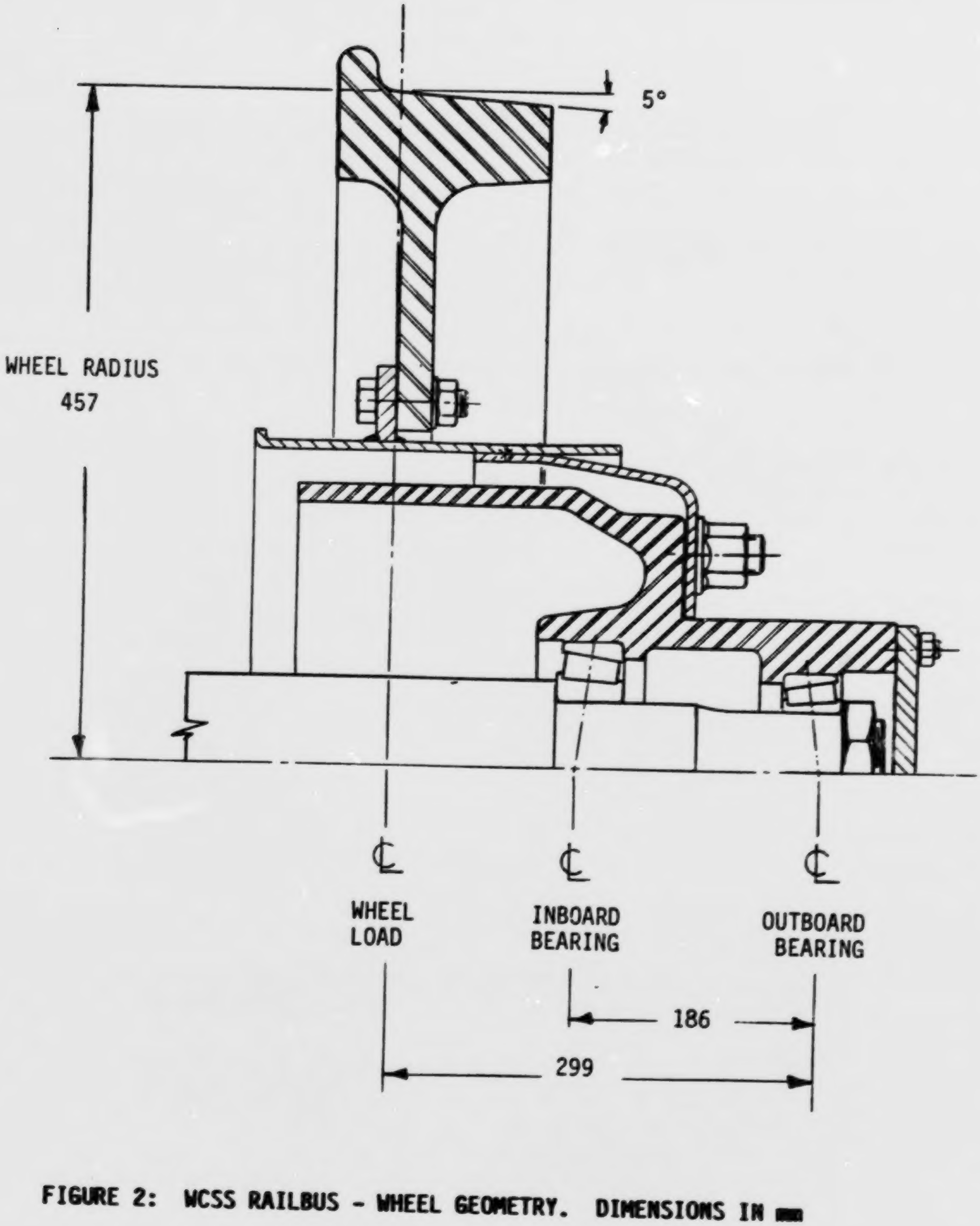

5°
WHEEL RADIUS
457
℄
WHEEL
LOAD
℄
INBOARD
BEARING
℄
OUTBOARD
BEARING
186
299

FIGURE 2: WCSS RAILBUS - WHEEL GEOMETRY. DIMENSIONS IN mm

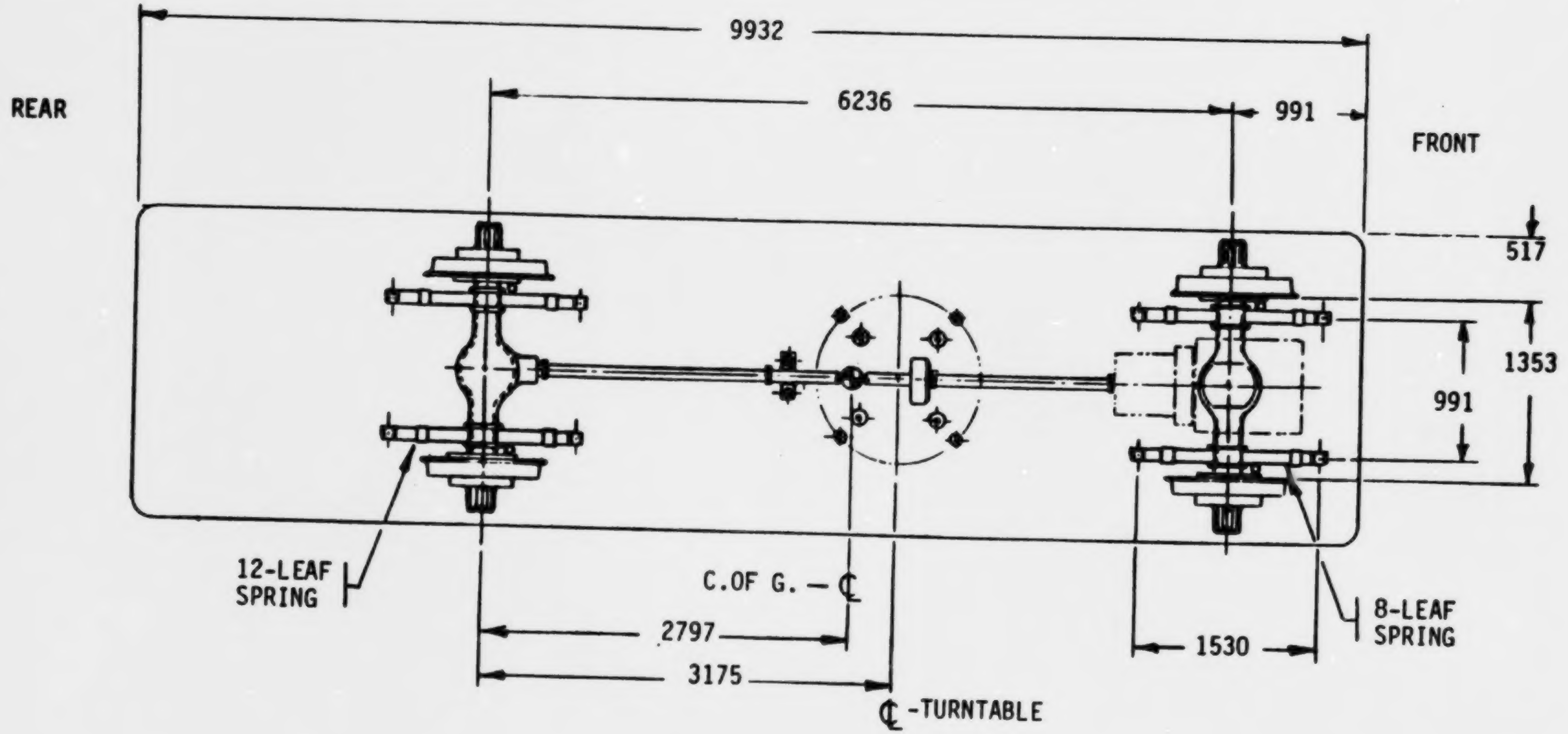

9932
REAR
6236
991
FRONT
517
1353
991
12-LEAF SPRING
C.OF G. — ℄
2797
3175
℄-TURNTABLE
1530
8-LEAF SPRING

FIGURE 3: WCSS RAILBUS - SUSPENSION DIMENSIONS IN mm

of rubber bump stops to improve vehicle ride comfort while in a loaded configuration. All other suspension surfaces and support equipment appeared to be adequate and in good condition.

During the first few weeks that followed the start of the test program, an attempt was made to mathematically model the railbus and its unique suspension system on an in-house program simulator - an HP 1000 computer was used. Detailed suspension measurements were taken by on-site test personnel and an engineering analyst in order to develop and model reasonable lateral and vertical ride parameters. Following a preliminary investigation and sample model runs, it was concluded that an adequate dynamic simulation would be unlikely to be achieved given the constrained timescale, and that program activity should be directed towards actual observations and ride measurements on the subject vehicle.

2.1.4 Driveline and Brakes

The vehicle driveline including universal joints, supports, and shafts were inspected for wear, end play, and cracks. The drivetrain was found to be generally in good condition.

The service brakes (drum-type at each wheel) were checked, tested and found to be in good operating condition.

The emergency-brake unit located mid-way along the drive-shaft to the rear axle could not be thoroughly inspected due to its restricted location over the turntable. The unit appeared to be adequate and its operation satisfactory. Relocation for serviceability was recommended for a later modification to the vehicle design.

2.1.5 Engine and Auxiliaries

The railbus engine (Detroit Diesel 4L-53) and auxiliary drive systems were checked for fluid levels, condition, belt tensions and smoothness of operation. After some minor adjustment and topping off of fluid levels including the addition of engine oil (SAE ED30) and anti-freeze, the drive system was concluded to be ready for testing.

2.1.6 Driver Controls

An inspection was made of the various driver controls and monitoring equipment used for normal vehicle operation. Repairs, replacements and modifications suggested were as follows:

- Accelerator pedal - broken pedal was to be repaired;
- Dash Fuel Gauge - fuel tank sender and dash gauge was to be replaced;

- Master power switch - was to be relocated from the LH lower luggage area to the LH wall, next to driver's seat.
- Speedometer - not properly calibrated and was to be adjusted.

2.1.7 Turntable and Hydraulics

The vehicle's turntable, structure and hydraulically operated controls were inspected for leaks, cracks and adequacy of design for the system. The system, although complicated in appearance, appeared to be sufficiently supported and in good general order. The hydraulic cylinders and control system, which lifts and turns the vehicle during normal turning procedures was tested and determined to be satisfactory - except for an unequal lifting characteristic (the front of the vehicle lifted first)

The turntable gear and undercarriage appeared to be reasonably protected from interference with any forseeable snow build-up which may occur during normal winter operations, however, modifications, if required, were postponed for further observations under winter conditions.

Measurement made of the turntable location, together with results taken of wheel loads (after addition of towing brackets) and axle locations, suggested the turntable was not originally located over the vehicles' centre of gravity. Following the addition of towing brackets,the vehicles' centre was determined to be 350 mm (14 in) rearward of the existing turntable's centre.

2.1.8 Pilot

The measured height of snow-plow or pilot's bottom edge to a point at the top-of-rail head was determined while the vehicle was in an unloaded configuration. The left and right-hand sides measured 70 mm (2.8 in) and 76 mm (3.0 in) respectively. Minimum CNR specified clearance is 76 mm for all vehicle configurations, including a loaded condition.

2.2 VEHICLE OPERATIONAL REQUIREMENTS

An engineering assessment was made of the vehicle design in consideration of the CN and CTC technical requirements prior to future operation on the CN Rail Line (Ref 4). The following summarizes the vehicle additions required:

2.2.1 Driver Safety Screen

A driver safety screen was to be designed and installed between the driver and passenger areas. The screen would provide a safety barrier for the driver.

2.2.2 Vehicle Towing

Towing brackets were to be fabricated and installed for the attachment of a light-weight towbar assembly to either end of the Railbus.

2.2.3 Rerailing Hard Points

Additions to the vehicle frame for hard points to be used during a rerailment exercise would be made, if required, prior to actual tests. It is anticipated 6.0 mm (0.25 in) checkered plates would be welded to the bottom of the rear frame extension and also near the pilot's main frame under the vehicle's front bumper.

2.2.4 Classification Lights

Two exterior forward-facing white flood lamps were to be mounted over the driver's location. Also, two each of red and green lamps were also to be mounted at the rear of the bus, near the roof line, as per CN and CTC technical requirements.

2.2.5 Deadman Switch

In the event the driver became incapacitated during Railbus operation, the vehicle would be fitted with an emergency system to safely stop the vehicle.

2.2.6 Engine Noise

Initial assessment of the vehicle during a trial demonstration suggested an attempt should be made to reduce the noise level emitted into the bus from the forward mounted engine drive assembly. An accoustic cover over the engine hood was recommended for installation. Additional recommendations made for further noise level reductions to be implemented prior to a CN Rail demonstration include:

- Isolating the exhaust-pipe from vibrating against the bus body;
- Addition of a heavy rubber pad (6.0 mm) to the metal floor area;
- Addition of an inlet silencer to the engine's air-intake manifold;
- Replacement of the air-intake filter from a high restriction wet-type to a low restriction dry-element type;

- Re-routing the exhaust-pipe to reduce the number of bends;
- Reducing the engine's maximum operating speed from 3,100 rpm to 2,600 rpm while still maintaining a vehicle maximum speed of 80 kph;
- Improving performance and reducing the speed of the engine's radiator fan.

3.0 PREPARATION FOR TESTING ON THE INCO LINE

3.1 TRACK FACILITIES

As TTL would require access to INCO railway facilities for testing and mileage accumulation, arrangements were made with Mr. M. Babulic, Superintendent Transportation. On-site test personnel were given a review of the operations and a tour of the Thompson Railway yard. The preparatory work included the following considerations:

- INCO railroad operations is governed by a hand book titled "Standard Gauge - Transportation Standard Practice" (Ref. 5). The hand book encompasses 10 sections designed to cover all aspects of railroad operations.
- On duty, train and track employees are required to have a copy of the hand book in their possession and possess a working knowledge of the regulations contained therein.
- "Timetables", a prerequisite on common carrier railroads, are not in use on the INCO rail line. INCO's safety rules, operating rules and special instructions are all contained in the hand book.
- Sidings or passing tracks for meeting or passing of trains are non existent between Thompson and the mines.
- A "wye track" is located at both ends of the Thompson-Pipe Lake line. The "wye" arrangement is necessary for turning unit trains and maintenance equipment.
- Main line and yard movements are controlled by the yard office. Train crew and maintenance staff are issued verbal instructions as required. Before the actions are acted upon, the employee receiving the verbal instruction must repeat same for accuracy.
- Train crews are generally a 2 man crew consisting of an engineman and brakeman. The engineman is charged with the responsibility of safe operating practices during the discharge of duty.
- Motor car set offs are strategically located along the railway right of way to enable the track maintenance forces to clear the main track for anticipated traffic.
- Contents of the hand book and operating techniques were studied carefully to ensure that the TTL employees while on the INCO-Pipe railway line were operating according to INCO operating rules.

- With production terminated at Pipe Lake mine, the track between Thompson and the mine was available to TTL for testing without interruption. A positive operating procedure was set with INCO's transportation office to use the track on a daily basis. In the event that an unexpected rail move would be required, we were to be contacted on the vehicle equipped mobile telephone to firm up the arrangements.

- Third party access to INCO facilities was arranged with TTL coordinating their movements and the on-site supervision.

3.2 DRIVERS AND TRAINING INSTRUCTIONS

It had originally been intended to use an INCO engineman to operate the railbus, who would be familiar with the local operations. As the TTL employees had become sufficiently proficient with the railbus, INCO agreed that TTL would use an engineman on the initial voyage only and operation of the railbus would continue under the control of the test employees for the duration of the program.

3.3 TEST SITE

The railbus was operated from Thompson to Pipe Lake and return (40 km either direction). The trip was made to familiarize test site personnel with the physical characteristics and track grades of the rail line and to identify a suitable "test site". A test track section of 2 km in length was chosen between mile markings 16 and 18.

This area was selected as the tests required 1.6 to 2 km of reasonably good track where speeds of 72 to 80 km/hr could be attained for specific tests. Curving and switches tests were carried out in the wye at Thompson yard.

3.4 REPAIR FACILITIES

Arrangements for tools, spare parts, equipment and repair facilities were arranged as follows:

- Test instrumentation and equipment were shipped from Kingston.

- Arrangements were set with local vendors for additional equipment and tools (when required).

- The drop pit area of the INCO car shop was made available to test personnel for vehicle repair and modification. As INCO had their own operational needs, the space was available on a daily approval basis. This arrangement proved very satisfactory. INCO personnel and equipment was also made available on an approved daily basis when required.

3.5 LIABILITY AND VEHICLE INSURANCE

Personnel, liability and vehicle insurance was arranged with Tomenson Inc. between INCO Manitoba Division and AII Transportation Technology Ltd., with the insurer being "Commonwealth Insurance Company" Policy No. CRX5020.

4.0 INITIAL VEHICLE PREPARATION

Various features of the WCSS railbus were inspected and reworked during the first few weeks that followed the start of the test program on 02 September 1985. Wheel surfaces and mounting faces were trued, vehicle structural components added, and instrumentation and test equipment adapted.

The following section summarizes the changes made to the Railbus prior to the start of the operational test and mileage accumulation program to be carried out on the INCO Railway line. The work was performed with the assistance of the INCO maintenance shop personnel and employees of TTL.

4.1 VEHICLE IMPROVEMENTS

4.1.1 Wheels

All four wheel were remachined using an AAR (American Association of Railroads) 1:20 profile and all wheel flats removed from the running surfaces. Wheel mounting faces were machined to assure trueness of wheel and vehicle tracking.

4.1.2 Fuel System

The fuel system had been reported to give periodic symptoms of fuel starvation to the engine. An additional in-line fuel filter and pump was added at the fuel tank area to boost system pressure and remove contaminants prior to entering the engine filters.

4.1.3 Driver Controls

An inspection and subsequent improvement was made of the various driver controls and monitoring equipment used for normal vehicle operation. Repairs, replacements and modifications required were as follows:

- Accelerator pedal - broken pedal was repaired (by INCO);
- Dash Fuel Gauge - fuel tank sender and dash gauge were replaced;
- Master power switch - was relocated from the LH lower luggage area to the LH wall, next to driver's seat.
- Speedometer - an attempt was made to re-calibrate the dash meter (off by nearly 10% of true reading), however it was concluded that a predetermined calibration chart would be used during actual test runs (Table 1).

INDICATED SPEED (MPH)	ACTUAL SPEED (MPH)
0	0
5.0	4.3
10.0	8.6
15.0	13.0
20.0	17.3
25.0	21.6
30.0	25.9
35.0	30.2
40.0	34.5
45.0	38.9
52.1	45.0

TABLE 1: SPEEDOMETER CORRECTION FOR 36" RAIL WHEEL (CIRCUMF. = 114")

4.1.4 Engine Controls

A driver activated engine high-idle control system was installed to aid in the vehicle warm-up and improve the performance of the hydraulic pump for operation with the turntable and re-railing winch. The engine shut-off was converted to be air-electric operated to permit disabling of the engine via the master power switch.

4.1.5 Engine Noise

Initial assessment of the vehicle during a trial demonstration suggested an attempt should be made to reduce the noise level emitted into the bus from the forward mounted engine and transmission assembly. A 50 mm (2.0 in) thick acoustic cover was installed over the engine hood.

4.2 EQUIPMENT INSTALLATION

In response to an engineering assessment and in consideration of the CN and CTC technical requirements prior to future operation on the CN Rail Line (See Section 2.2), some additions were made to the original Railbus design. The following summarizes the vehicle preparation carried out:

4.2.1 Pilot

The measured height of the snow-plow or pilot's bottom edge to a point at the top-of-rail head was determined while the vehicle was in an unloaded configuration. The left and right-hand sides measured 70 mm (2.8 in) and 76 mm (3.0 in) respectively. Minimum CNR specified clearance is 76 mm for all vehicle configurations, including a loaded condition.

The pilot's height was modified by slotting the mounting brackets and readjusting the height clearance to 127 mm (5.0 in) for an unloaded vehicle condition. Suspension travel reduced the height to nearly 100 mm (4.0 in) when the vehicle was loaded to its maximum specified weight of 12,020 kg (26,500 lb).

4.2.2 Driver Safety Screen

Since the vehicle will only be carrying CN operators and program observers during its initial test period, a suitable clear lexan driver safety screen to separate the driver from the passenger area was designed but not yet fabricated or installed. Pending further negotiations with CN Rail, the screen would be installed prior to the passenger service demonstration if required at that time.

4.2.3 Vehicle Towing

Towing brackets were fabricated and installed for the attachment of a light-weight TTL designed towbar assembly (Figure 4) to either end of the Railbus. Addition of the rear vehicle bracket included the installation of a frame extension which would serve as the mounting platform when repositioning the towing winch.

4.2.4 Rerailing Hard Points

Additions to the vehicle frame for hard points to be used during a rerailment exercise would be made, if required, after initial tests. It is anticipated 6.0 mm (0.25 in) checkered plates would be welded to specific area at the bottom of the rear frame extension and also near the pilot's main frame under the vehicle's front bumper.

4.2.5 Classification Lights

Two exterior forward-facing white flood lamps were mounted over the driver's location. Also, two each of red and green lamps were also mounted at the rear of the bus, near the roof line, as per CN and CTC technical requirements. The lights are controlled by driver activated switches.

4.2.6 Deadman Switch

In the event the driver suffers incapacitation during Railbus operation, the vehicle was fitted with an emergency system to safely stop the vehicle. Upon release of a floor mounted foot-petal, the activated system would automatically bring the engine to a slow idle (600 rpm), bring the transmission (torque converter) to neutral and gradually apply the service brakes.

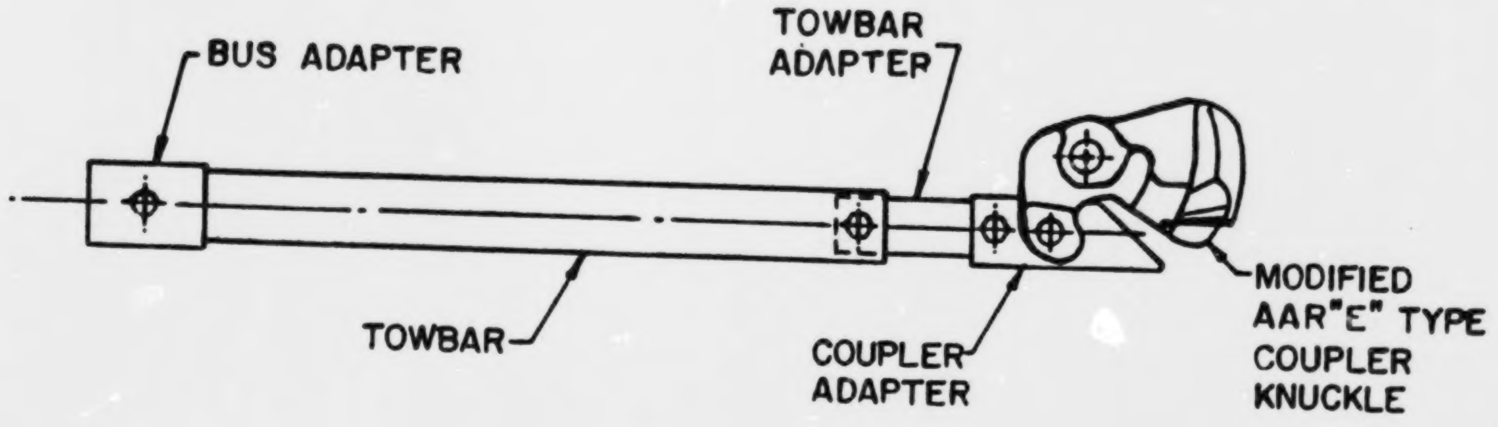

BUS ADAPTER
TOWBAR ADAPTER
TOWBAR
COUPLER ADAPTER
MODIFIED AAR"E" TYPE COUPLER KNUCKLE

FIGURE 4: RAILBUS TOWBAR ATTACHMENT

4.3 INSTRUMENTATION

The Railbus was fitted with miscellaneous test instruments prior to the start of the INCO test and mileage accumulation program. Equipment included hand-held instruments and the capabilities for video and/or actual measurements to be taken of:

- Noise levels (interior);
- Vibration levels (lateral and vertical);
- Ride comfort;
- Wheel behaviour;
- Curving behaviour;
- Switching behaviour;
- Stability;
- Mileage accumulation.

The following additions were made to the vehicle in preparation for the test trials:

4.3.1 Accelerometers

One 5G and another 30G accelerometer for lateral and vertical measurement respectively, were mounted to a bracket located at the bottom of the front axle beam. Acceleration rates and forces transferred to the axles through the wheel-to-rail interface would be measured with the on-board two channel strip chart recorder.

4.3.2 Hubodometer

A wheel hubodometer was attached to the center of the front left-hand wheel hub to enable mileage accumulation and service intervals to be monitored on a daily basis.

4.3.3 Video Cameras

The Railbus was fitted with four video cameras to observe wheel behaviour on both front and rear axles. Two on-board video monitors and a VHS video tape recorder were used to monitor the behaviour of the wheel-to-rail interface while on tangent and curved tracks as well as wheel behaviour during switching test trials.

4.3.4 Miscellaneous

Additional equipment fitted to the Railbus for use and instrumentation during the test period included:

- Gasoline powered portable generator - 110 VAC;
- Hand-held dB sound measuring meter;
- British Rail Ride-Meter (BRRM);
- Calibration instruments;
- Interior lighting and power outlets - 110 VAC;
- Work bench and storage racks.

5.0 VEHICLE MODIFICATIONS

5.1 BACKGROUND TO THE MODIFICATIONS

The vehicle modifications were carried out at program midpoint and were a result of observations made by TTL engineering following a review of the initial several weeks of operational testing while on the INCO Railway Line. The design, intended application and anticipated reliability were reviewed in light of the accumulated experience detailed in Section 6.0 and a series of vehicle improvements carried out . This modification work was implemented by the subcontractor, Winnipeg Coach Sales and Service (WCSS), and the Railbus was subsequently returned to Winnipeg for repairs.

5.2 TURNTABLE

The preparation work carried out earlier had led to the addition of a rear-mounted frame extension, winch platform and tow-bar bracket. When taking into consideration a full fuel tank, and relocation to the rear of the tow-winch and on-board vehicle supplies and equipment, the turntable's lifting centre was estimated to be nearly 355 mm (14 in) forward of the vehicle's true centre-of-gravity. Observations also made by TTL test personnel, following several weeks of testing, reported unequal wheel lift, difficulty in re-aligning the Railbus onto the track (after a lift) and concerns about stress cracks in the support guides.

As a result of these observations and a subsequent failure in the turntable hydraulic lift assembly, the location of the turntable and hydraulic lift assembly was relocated to coincide with the centre-of-gravity of the bus. The location was determined, with the aid of wheel load cells, to be 2,820 mm (111.0 in) forward of the rear axle. The turntable's frame and guide assembly were aligned and re-enforced, and the hydraulic lift rams (4) were upgraded to 50.8 mm (2.0 in) diameter rods from 31.3 mm (1.25 in).

Following the modification, the on-board turntable assembly appeared to perform well initially and the previous difficulties reported were corrected. Location of the reworked turntable relative to the vehicles measured wheel loads is shown in Figure 5. The turntable's centre was determined to coincide within 12 mm (0.5 in) of the vehicle's measured centre of gravity with a full fuel tank.

LOAD LOCATION	WHEEL LOADS (kg)	
	UNLOADED	LOADED
R.H. FRONT	2244	2638
L.H. FRONT	2440	2856
R.H. REAR	3124	3429
L.H. REAR	2669	3057

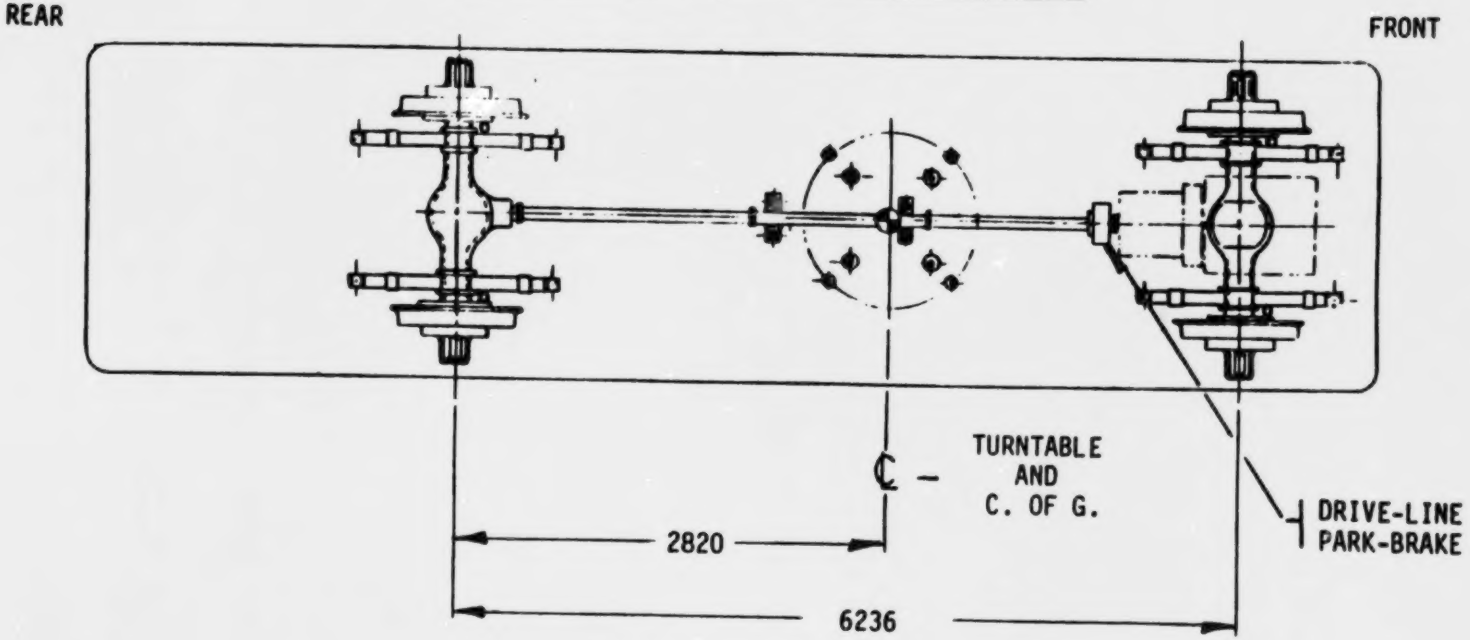

REAR
FRONT
℄ – TURNTABLE AND C. OF G.
DRIVE-LINE PARK-BRAKE
2820
6236

FIGURE 5: MODIFIED VEHICLE GEOMETRY DIMENSIONS IN mm

5.3 SUSPENSION

Reports of the vehicle's underframe bottoming on the axle during several test runs resulted in a close assessment of the suspension elements. Observations concluded that only 25 mm (1.0 in) of front-shock travel was available in the present configuration when the vehicle was unloaded. Rubber bump-stops on both front and rear axles were non-existant.

The mounting brackets for both front shock-absorbers were relocated to permit 90 mm (3.5 in) travel during normal vehicle operation and rubber bump-stops were added to both front and rear axles.

Although preliminary test results on ride quality resulted in satisfactory performance of the current leaf-spring arrangement, data was gathered and a sample installation inspected of a suspension improvement which may later be added to the Railbus design. The suspension improvement centred on the adaption of complete rubber isolated supports which adapt to the current leaf-springs arrangement and was claimed to reduce noise penetration and soften the vehicle ride (see Figure 6). This improvement was not carried out during the program as it was concluded that the ride was acceptable and the modification not cost-effective.

5.4 WHEELS AND BEARINGS

The wheel bearings were removed and inspected and determined to be in relatively good condition. In anticipation for the severe winter temperatures which may affect the reliable operation of the Railbus, the bearings were thoroughly washed and re-packed with a low temperature grease suitable for -55°C (SKF Type LGHT2). The standard grease removed was suitable for only -30°C and had the appearance of some dirt contamination.

Wheel mounting reliability was also improved through the addition of five more wheel nuts to each of the four wheels.

5.5 DRIVE-LINE

Preliminary test results indicated severe vibrations were being transmitted to the vehicle's structure floor over the location of the turntable assembly. Inspection of the drive-line and its associated supports showed the rubber mounts to be fairly stiff and likely hardened from age. The confined location of the emergency brake unit situated over the turntable assembly prevented a close observation of the unit. It was concluded upon observation that the drive shaft, drive supports and parking brake unit would be removed for a thorough inspection.

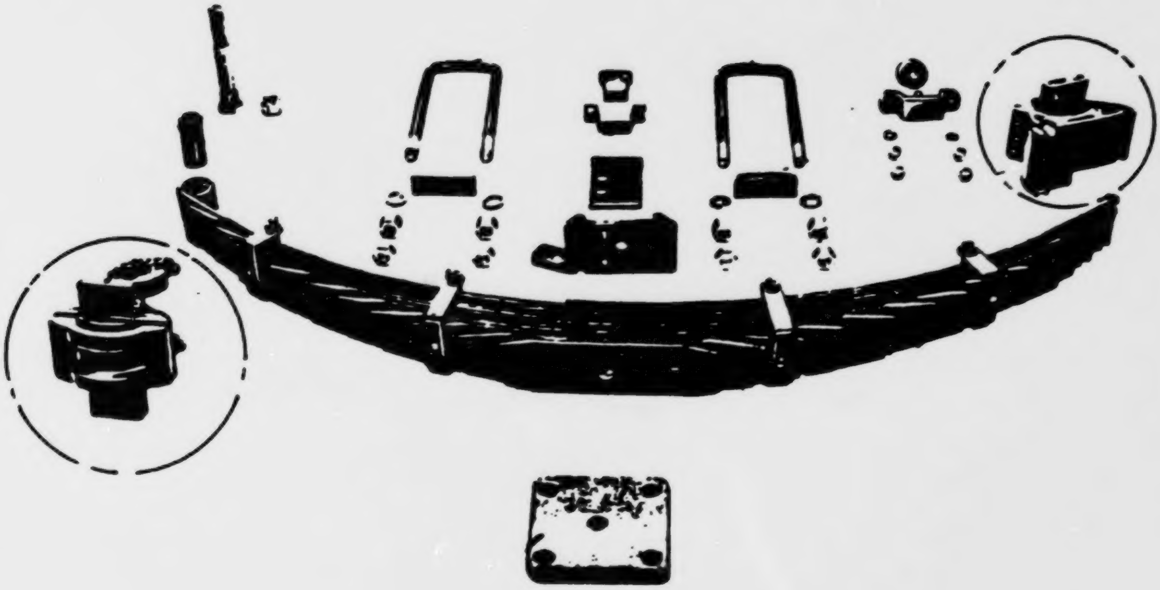


FIGURE 6: ALTERNATE SUSPENSION DESIGN

The mid-body mounted emergency brake-unit was therefore removed from the drive-line section over the turntable and an alternative brake design mounted to the rear-end of the transmission. Alignment of the drive-shafts was checked from the engine to the rear-axle, new rubber supports added (where required), and the indexed relationship between adjacent universal joints properly set.

Inspection of the removed drive-line brake-unit gave evidence that the drum was once overheated and was likely to be out-of-balance. Test runs subsequent to this up-date resulted in an improved ride quality with mid-floor vibrations being greatly reduced at all vehicle speeds.

5.6 ENGINE NOISE

The addition of the engine-hood cover had reduced the interior cab noise level by a measured 5 dB at a vehicle speed of 80 kph. Further attempts were made to better improve driver and passenger comfort levels, previously measured prior to modifications at 93-95 dB (recommended maximum is 90 dB).

The wet-type air-intake cleaner was replaced with a dry-type unit noted for its lower restriction characteristics. Acoustic absorbing material was used to line the air-filter compartment within the vehicle. An air-silencer was added to the engine's intake manifold to further aid in reducing engine noise. Additional rework included improved isolation of the exhaust pipe from the Railbus frame and the re-routing of the exhaust pipe to reduce the number of bends and lower the exhaust backpressure.

Following a preliminary retest of the railbus after the modifications were put into place, interior noise level measurements of 83-86 dB were observed at a vehicle speed of 80 kph.

5.7 ENGINE RELIABILITY

Previous reports of engine starter problems has led to the replacement of the unit. Inspection of the removed starter indicated a cracked solenoid casing and a ground fault in the wiring had led to its failure.

The fuel tank was found to be contaminated with dirt and sediment. The tank was removed and the interior scraped clean, new gaskets installed and pressure tested for air leaks. An additional filter-screen was installed within the tank prior to the outlet tube to the primary fuel-pump. The primary fuel filter was relocated to operate between the fuel pump and the fuel tank.

An engine-stop was to be added to provide an essential engine-kill feature in the event of a loss of power (air and electrical.)

5.8 RE-RAILING WINCH

The hydraulically operated re-railing winch was relocated and mounted onto the frame extension at the rear of the bus. The winch, which is controlled from the driver area within the bus, was fitted with approximately 25 m (80 ft) of 11 mm (.44 in) diameter towing cable. Observation made of the winch operation indicated the cable drum would rotate at a maximum speed of only 1 RPM - much slower than the recommended speed of 10-15 RPM. This item requires further corrective action to include a correctly matched hydraulic motor and pump.

5.9 RAIL SANDERS

Two vehicle-mounted rail sanders were to be installed to assist in the traction and braking ability of the Railbus. Holding tanks, hoses and electrically activated control-valves would be assembled within the rear axle area for sand to be dispersed to the rear traction wheels. The system would be activated and the rate controlled from the driver's console. This work was completed at the end of the testing phase.

5.10 CN RADIO

A CN specified radio was to be installed in the Railbus and mounted near the driver's area. The radio would remain within the vehicle at all times and would have sufficient transmission range for the territory to be operated within. The required mounting and wiring was installed.

6.0 TEST PROGRAM

6.1 GENERAL DESCRIPTION

The vehicle was tested during several weeks of operational trials conducted on the INCO Railway Line. Test measurements and data recorded followed procedures outlined in the test plan (Ref. 6). Results from the tests are detailed in the test report, included as Appendix 1 and summarized in this section.

The test program was basically divided into two phases:

- Baseline tests to be conducted prior to the mileage accumulation; and
- Vehicle retests to be conducted following a mileage accumulation of 3000 km.

Several special tests were performed during both phases to evaluate the vehicle reliability and acceptability for operation on the CN Line.

The test requirements specified that the vehicle's performance would be measured and reviewed in a comparative manner to examine the effect of modifications and of various operational speeds. For these tests (i.e., noise, ride quality, stability, vibration, etc.) a relatively level track section was chosen - INCO Mile No. 16 to 18. The main switch yard outside INCO's maintenance and production facility was selected as the secondary test site for observations and video recordings of wheel behaviour through various curves and switch types.

The major portion of the test program was scheduled to be completed during the first phase of the program with the vehicle in its unladen configuration (10310 kg) and in its original state of modification. Vehicle retests were primarily concerned with vehicle behaviour following limited improvements to its design and in its fully laden configuration (12020 kg). Review of Table 2 will outline the tests completed and the vehicle configuration used during the two phases of the test program.

In general very little trouble was experienced with the vehicle in terms of its conversion to rail operation. Curving, stability, ride, braking and behaviour in switches was considered to be very acceptable. The major problem areas such as engine failing to start and other miscellaneous problems affecting reliability were mainly connected with the advanced age and modification history of the vehicle.

TEST	DESCRIPTION	VEHICLE CONFIGURATION INITIAL	VEHICLE CONFIGURATION MODIFIED
Noise	Measure interior and wayside noise levels	Unladen	Unladen
Vibrations	Measure lateral and vertical axle acceleration rates	Unladen	Unladen Laden
Ride Quality	Measure interior ride comfort using British Rail Ridemeter Method	Unladen	Unladen Laden
Stability	Determine vehicle's maximum safe operational speed	Unladen	Unladen Laden
Curving	Identify tendency to derail at various operational speeds	Unladen	Unladen Laden
Switching	Identify tendency to derail, damage switches or follow wrong alignment	Unladen	Unladen Laden
Fuel Consumption	Determine fuel consumption in general use	Unladen	Unladen Laden
Wear and Reliability	Determine wear rate of wheels and reliability of axle bearings	Unladen	Unladen Laden
Rerailing	Evaluate winch operation and rerailment techniques	-	Unladen
Turntable	Evaluate design and reliability	Unladen	Unladen
Energy	Evaluate vehicle battery life	-	Unladen
Drawbar	Evaluate operation for emergency rescue	Unladen	-
Deadman Switch	Evaluate operation for emergency stops	Unladen	-
Power Shut-Off Switch	Evaluate operation for emergency stops	Unladen	-
Mileage	Accumulate 3000 km of operational experience	Unladen	Unladen

TABLE 2: SUMMARY OF TESTS

6.2 SUMMARY OF TEST RESULTS

The WCSS Railbus was tested as described during several weeks of operational test trials conducted on the INCO Railway Line. A summary of observations made on the design and operation of the vehicle are as follows:

Vehicle Noise - Following the addition of sound deadening materials to the engine area and improvements in drive-line design (vibrations), the interior noise levels measured at the operator's location was judged as acceptable (85-87 dB(A) at 72 km/h). This level was 93 dB(A) before modifications were carried out.

Vehicle Vibrations - Lateral and vertical accelerations of the vehicle axles during normal operation were observed to be very acceptable and substantially lower than initially predicted - average dynamic axle accelerations for the fully laden vehicle were measured at 0.9 G, with peaks to 4.2 G, for the vertical and 0.5 G, with peaks at 1.5 G, for the lateral rate.

Ride Quality - Measurements of ride quality for both laden and unladen vehicle configurations were recorded on a British Ride meter. The Railbus was tested at an operational speed of 72 km/h. An average BR Number of 3.6 was measured for the vertical ride, which corresponds to a "just satisfactory" quality of ride. An average BR Number of 3.8 "operable", was measured for the lateral ride over the front axle falling to a value of 3.0, "satisfactory", at the mid and rear position. In general, the ride quality for the WCSS Railbus is considered as "just satisfactory".

Wheel/Rail Interface - In consideration of the vehicle's stability, curving behaviour and switching behaviour as observed and recorded on body mounted video cameras, the Railbus was judged as very acceptable for operational service at all rail speeds, up to and including 90 km/h.

Fuel Consumption - Based on several representative service runs, the WCSS Railbus in typical operation is likely to consume fuel (diesel) at an average rate of 5.43 km/L (15 mpg).

Reliability and Wear - The wear observed and measured on the wheel bearings and wheel running surfaces after over 3347 km of operational use was judged as very acceptable. The highest wheel profile wear (.75 mm) was measured on the front right-hand wheel surface, at the flange radius. Some minor wheel flats were observed on all wheels (from slide braking) however they were judged as not being a serious problem.

Rerailing and Winch Operation - The design displacement of the hydraulic pump and motor utilized to drive the winch was judged as unacceptable - the winch would rotate at a maximum rate of only 1 RPM. As a result, a suitable rerailment test using the winch could not be demonstrated and had to be postponed till the operation of the device was improved. It is noted however, the WCSS Railbus had sufficient drive-axle traction (without sanders) in order to back itself onto the track when the vehicle front wheels derailed at a snow and ice-packed road crossing.

Turntable System - The hydraulic lift cylinders failed during the early part of the test program after nearly 50 vehicle lifts were performed. Primarily attributed to the mismatch of the turntables lift-centre relative to the vehicle's centre-of-gravity, the vehicle has been recently modified to correct the problem and upgrade the turntable's capabilities. However, erratic lift behaviour in cold weather conditions has continued to plague the reliability and operation of the system. The system design has been judged as unsatisfactory for continued use in its present configuration.

Energy - Load Current measurements taken from the battery during a simulated emergency service demonstrations (i.e. engine off, emergency heater on, some interior lighting on) indicated the battery life could satisfactorily sustain the vehicle's occupants during an emergency for a period of 24 hours. The auxiliary or emergency heater, however, had an inadequate heat output in cold weather conditions and requires improvements in its operation.

Draw-Bar Operation - Tests in which the Railbus was pushed and pulled at either end using a motive power unit and tow-bar attachment indicated the design and operation were satisfactory.

Deadman Switch and Brakes - The design and installation of the device for stopping the Railbus during an emergency was judged as satisfactory. The vehicle deceleration rate while stopping was measured at approximately 1.1 m/s^2.

Emergency Engine and Power Shut-Off Switch - Operation of the master power switch was determined to be satisfactory for disconnecting the auxiliary electrical circuits from the battery, however, the switch was unable to simultaneously disable the engine operation. Given an emergency, it is suggested an alternate mechanical means be adapted to quickly and reliably shut-off the engine power.

Mileage Accumulation - During the course of the test trials, the WCSS Railbus had accumulated 3347 km of operational track experience.

6.3 IMPACT OF INCREASING MILEAGE

There were a number of vehicle features which showed some deterioration as a result of increasing mileage on the vehicle, necessitating improvement or rework during the program. They were:

- The turntable required rework after some 50 operational lifts, corresponding to perhaps a few weeks of operation on the intended CN route.
- Fuel contamination gradually clogged filters and lines causing engine reliability problems requiring system cleaning plus improved filtration equipment.
- Engine starter was a reconditioned unit and failed requiring replacement.

In contrast the following features which had been a source of concern at the start of testing proved to be relatively unaffected by increasing mileage, namely:

- Wheel wear was negligible.
- Bearing wear was negligible with the exception of one bearing showing signs of contaminated grease.
- The suspension, once set up properly, showed no deterioration.
- The wheel assembly showed no signs of deterioration.

6.4 SUITABILITY OF VEHICLE FOR PASSENGER OPERATION

The vehicle is clearly a demonstration prototype rather than a fully developed production vehicle. As such it is suitable for a passenger demonstration of initially limited duration, say a few months, but the following is recommended based on the experience to date.

- Further trials be carried out in full winter conditions before passengers are carried, in order to eliminate any remaining problems not discovered during Fall weather conditions.
- An agressive maintenance and inspection procedure be followed during any passenger operation to maintain acceptable reliability and safety.
- A "train rider" familiar with the vehicles design and operation be carried on any passenger demonstration service undertaken.

6.5 RESULTS OF TESTS ON VIA TRAIN

For comparison purposes a brief test was carried out on the current VIA train operating out of Thompson. Ride and interior noise measurements were made on 20 November 1985 using the same test equipment and personnel as for the WCSS vehicle. The train consisted was:

- o 2 locomotives
- o 2 steam cars
- o 1 luggage car
- o 2 day cars
- o 1 dining car
- o 2 sleeper cars.

A total of 27 passengers were carried.

Immediately noticeable was the extremely low noise levels in the range of 61 to 65 dB(A) at 50 km/hr rising to 62 to 68 dB(A) at 70 km/hr depending on location within the passenger coach.

British Rail Ridemeter measurements gave results of between 2.0 and 2.3 for lateral and 2.1 to 2.6 for vertical ride at 50 km/hr depending on location within the vehicle. At a higher speed of 70 km/hr the lateral ride values increased to the 2.3 to 2.7 range and vertical ride to the 2.3 to 2.7 range. In contrast at a slightly higher test speed of 75 km/hr the WCSS vehicle showed ridemeter values for lateral and vertical ride in the 3.0 to 3.4 region. These numerical values correspond to a rating between "good" and "satisfactory" for the VIA train and between "satisfactory" and "Just Satisfactory" for the WCSS vehicle. It should be pointed out that the quality of the CN track was better than the INCO track, since this latter track has not been in regular use for over a year and no maintenance has been carried out.

Clearly the factor requiring attention is the high noise levels of typically 80 to 85 dB(A) in the WCSS vehicle.

7.0 PLANNING FOR OPERATION ON THE CN LINE

The overall objective of this task was to identify the applicable rules of the Uniform Code of Operating Rules (UCOR) and Canadian Transport Commission (CTC), prepare a mode of operation, and subsequently prepare a plan to implement the chosen strategy for a winter demonstration of the vehicle on the specified CN railway line.

To achieve the objectives, an in depth review was initiated of:

- Rules
- Train and Traffic Control
- Operating Practice
- Implementation of the Chosen Operational Strategy
- Baggage Control
- Passenger Safety in the event of vehicle breakdown.

The demonstration of the WCSS railbus will take place in a real rail environment, subject to all the seasonal elements of a winter operation.

7.1 RULES

The Uniform Code of Operating Rules, Revision 1962 (Ref. 7) contains the rules and regulations governing train operations on common carrier railways.

Train movements are further controlled by current timetable, special instructions, bulletin form special instructions and Canadian Transport Commission general orders.

The designated test area for the test and demonstration is on the Thicket subdivision between mile 184.3 (Thicket Portage Station) and mile 213.3 (Pikwitonei Station) and on the Thompson subdivision between mile 0.0 and 30.5. The mode of operation on both subdivisions is the manual block system (MBS).

The sum of the Uniform Code of Operating rules are applicable in mainline and yard movements of trains and engines. Rules 321, 322, 323 are specifically designed for manual block system movements. These rules are supplemented by special instructions (system) number 2.0 of the current timetable No. 27 Prairie region, (Ref. 8) and dictate in what manner control of train and maintenance equipment will be exercised.

As references are made in this report to terms defined from the UCOR, a condensed definition list is provided as follows:

- Train: an engine or more than one engine coupled with or without cars, displaying markers.
- Engine: a unit propelled by any form of energy or a combination of such units used in train or yard service.

- Timetable: The authority for movement of regular trains subject to the UCOR: It contains special instructions relating to the movement of trains and engines in specific locations and for specific durations.

- Subdivision: a portion or area of a division designated by timetable.

- Engineman: the employee in charge of and responsible for the operation of an engine.

- Conductor: rule 106 of the UCOR - trains will run under the direction of the conductors. When a train is run without a conductor, the engineman will perform the duties of the conductor.

Applicable permissable speeds for each mode of operation are contained in the timetable. If tests of the WCSS rail indicate higher speeds than in the timetable are obtainable in a safe manner, exemptions will be requested from CN and CTC. Permanent speed restrictions are also contained in the timetable.

Specific speed restrictions referring to temporary track conditions are covered by train orders issued by the train dispatcher. Train orders relating to track or other condition, must be numbered consecutively, using a separate series of numbers and reissued if continuing in effect for a period of two weeks.

7.2 TRAIN AND TRAFFIC CONTROL

The movement of trains, engines, and maintenance equipment is controlled and supervised by the train dispatcher, subject to the rules, CTC board orders, and special instructions of the current timetable.

The train dispatcher is skilled in train movement and alert to react to operational delays and extraordinary circumstances. It is of paramount importance that the dispatcher be aware in advance of the operating plans for the testing of the WCSS railbus while on the CN line. It is of equal importance that the dispatcher be advised from the first point of communication of delays occurred enroute. This information will assist the dispatcher in the dispatching of opposing and following movements.

To effectively execute his duties, the train dispatcher has at his disposal:

- Uniform Code of Operating Rules (UCOR - 1962) (Ref. 7);
- Current Timetable (No. 27 - Prairie Region CNR - October 1985 (Ref. 8);

- Safety Rules and Instructions (CNR September 1972) (Ref. 9);
- General Operating Instructions - Revision (CNR June 1985) (Ref. 10);
- Regulations for Track Units and Maintenance (CNR July 1978) (Ref. 11); and
- Current Bulletin Orders and Notices (CNR - issued as required).

For the current designated test subdivisions, Current Timetable No. 27 - Prairie Region, CNR indicates that:

- manual block system is in effect. Rules 321, 322, 323 are applicable;
- rule 5 of the UCOR is modified. Times shown are information only, and contain no operating authority;
- rules 41 and 44 are applicable; and
- also contains the special instructions for MBS operation.

CN train crews, with TTL supervision of tests, working in harmony with the train dispatchers, should enhance a successful completion of the railbus test plan.

7.3 OPERATING PRACTICE

In response to a CN requirement, a CNR 2 man crew will be used at the outset of the testing and demonstration of the WCSS railbus on CN lines. Assignment of a regular crew (conductor and engineman) would be advantageous to the program to eliminate continual vehicle training of spare CN crew members.

Notice of a required CN crew should be given 10 days in advance of the required date, to permit a bidding process and subsequent crew selection to transpire. If the assignment was considered non-profitable or desirable by the train crews, junior employees would be assigned. In either scenario, the benefits are numerous by having a regular crew making the same moves on a daily basis.

A bunkhouse is maintained by the CNR at Thompson for train crew's rest and food preparation requirements.

A fixed or pre-determined ordering time should be arranged daily, Monday to Friday. The train crew will then be expected to report to the designated start area without benefit of a "physical" or telephone wake up call. In anticipation of an 08:15 departure time, a suggested ordering or crew call time would be 07:30. Routine crew activity from that time would be as follows:

- read and initial at the CN station the current bulletin orders and notices;
- verification of their railroad approved watches;

Saturday - Mixed train passes Thompson Junction at 13:40
enroute Wabowden. Does not run into Thompson.

Sunday - Passenger train arrives and leaves Thompson
08:15-09:45 enroute Thicket Portage and Wabowden.
Mixed train passes Thompson Junction 11:00 enroute
Gillam, does not run into Thompson.

In view of the foregoing review, it is concluded that a Monday to Friday operation shown in Table 3 would best suit the needs of the program.

Station	Arrive	Depart
Thompson		07:00
Thicket Portage	08:35	08:50
Pikwitonei	09:50	10:05
Thompson	11:45	

TABLE 3: WCSS RAILBUS TEST SCHEDULE - ONE TRIP PER DAY

At a later date, operation of a second round trip per day may be requested. Consideration will have to be given at that time to assigning a second train crew to the railbus or operating with one crew and paying considerable overtime to facilitate passenger shopping time in Thompson.

It is of importance that the railbus never be coupled to another train except for emergency retrieval, due to:

- construction of vehicle frame;
- absence of a train air braking system; and
- absence of standard drawbar and coupling arrangement.

7.4 OPERATIONAL REQUIREMENTS

The prerequisites for implementation of the chosen operational strategy are:

- Vehicle acceptance by the CTC and CNR;
- Crew assignment;
- Availability of bunkhouse at Thompson for the CN railbus crew;
- Crew transportation requirements (Thompson);
- Supply of portable and vehicle radios;
- Establish a local contractor for vehicle maintenance repairs, and monthly inspection;
- Establish a local janitorial service;

- Establish a supply of diesel fuel for railbus on a daily basis;
- Implement a daily check list and a monthly inspection list for the railbus;
- Implement a fault sheet for daily completion by the CN crew;
- Establish a daily operating report for completion by Operations Manager, to include: weather conditions, failures, delays and extraordinary occurrences;
- Establish a baggage handling procedure;
- Verify heavy duty and emergency equipment are on board the vehicle; and
- Implement a procedure for passenger safety and recovery in the event of a vehicle problem while in service.

7.5 PASSENGER BAGGAGE TRANSPORT

Baggage transportation and handling system similar to the airlines and common carrier railways is recommended to be implemented to reduce loss and claims. A string type attachable baggage check, pre-numbered, with the passenger retaining the detachable portion of the corresponding number. The passenger would be required to surrender his portion of the baggage check upon claiming the baggage.

Baggage compartments (lockers) are located underneath the railbus on either side. There is additional space at the rear on the exterior of the railbus. The usual luggage racks for hand baggage are located above the seating arrangement on the interior of the bus. Consideration will be given to eventually assigning the baggage compartments to specific destinations to speed up the offloading at each location.

The quantity of baggage to be transported is not certain at this time and will be addressed once again after initial experience.

With an estimate of 20 passengers per trip, it is anticipated the present baggage space is ample, providing that the transportation of boats, canoes, flammables, and animal carcasses as baggage is not permitted.

7.6 EMERGENCY PLANNING

In the event of vehicle failure, ongoing delay or derailment, the first concern will be that of safety and comfort of the passengers.

Railbus onboard resources readily available are:

- first aid kit;
- stretcher;
- supply of blankets;
- auxiliary heater;
- mobile telephone installed by Manitoba telephone system;
- CN two-way radio.

In addition:

- rerailing winch;
- portable tow and drawbar attachment suitable for either end of the railbus;
- length of towing chain or cable;
- switch broom;
- sledge hammer:
- shovel;
- axe;
- saw;
- fire extinguisher; and
- portable jack.

If a derailment, fire, crash or any form of tragedy occurs, once the passengers' welfare has been provided for, contact with the train dispatcher will be made immediately using one of the two onboard radios.

The train dispatcher will assess the situation from an operational standpoint and make arrangements for medical assistance, helicopters, advance notice to local hospitals and, if necessary, the auxiliary train.

8.0 CN AND CTC ACCEPTANCE

8.1 REVIEW OF CN AND CTC REQUIREMENTS

The CN and CTC requirements are detailed in Ref. 3. The specific vehicle changes that were implemented have been described in Sections 2.2 and 4.0. It was concluded during the planning stage of the program that a formal application would be made to the CTC detailing the approach to be taken to satisfy the requirements. This application would be in two distinct stages, the first for non-passenger operation and the second for non-revenue passenger carrying operation. These applications would request exemption in certain specific areas namely:

- bell;
- sill steps;
- ladders;
- running boards;
- sparks arresting system;
- hand holds; and
- coupling device.

The vehicle is equipped with a driver-activated drop-down step for passenger convenience and safety. Other items mentioned in the previous paragraph are considered inapplicable for this specific application.

Additional requests were made by the CNR for:

- protective barrier for the operator;
- daily inspection and maintenance of the vehicle; and
- modifications to support the vehicle weight for rerailing purposes in the event of a derailment.

These requests will be further considered and implemented, prior to operation on CN Rail's Thompson Line.

In consideration of the CN operation area, and the absence of centralized traffic control, crossing protection signals and public crossings at grade, relief on the items indicated above is recommended.

8.2 CTC APPLICATION

Based on the results of a review meeting held with TDC, CN and CTC at Thompson, Manitoba, 1985, it was recommended that the application to the CTC for non-passenger operation be submitted jointly by CN and TDC (Ref. 12). TDC submitted an advance application while the appropriate approvals were obtained within CN. This advance application included the data summarized in Table 4 and was submitted on 10 October 1985 (Ref. 13). It was concluded by the CTC that the application must be received directly from the operating railroad (CN) before any CTC authorization could be issued. CN's formal submission to the CTC for non-passenger operation on the Thompson-Thicket Portage-Pikwitonai route was submitted January 17, 1986 and CTC's authorization to allow operation was issued on 28 January, 1986 under Order No. R-38999.

ITEM	DESCRIPTION
1.	"Railbus Development and Demonstration Programme Presentation in Thompson, Manitoba, to the Technical Advisory Committee on 4 September 1985" presented by Transportation Development Centre (TDC) Montreal.
2.	"Railbus Presentation 4 September 1985 to the Technical Committee, presented by UTDC R&D, Kingston.
3.	Minutes of meeting of 4 September 1985 to Railbus Technical Advisory Committee.
4.	"Detailed Work Plan for Testing of WCSS Railbus on INCO Railway Line" by UTDC R&D, Kingston.
5.	"Test Plan for Testing of WCSS Railbus on INCO Railway Line" by UTDC R&D, Kingston.
6.	"Technical and Regulatory Requirements for Vehicle Acceptance on CN Railway Lines" by UTDC R&D, Kingston.
7.	"Tracking Ability Assessment of an Experimental Railbus Vehicle" by DSL Dynamic Sciences Ltd., Montreal.

TABLE 4: SUMMARY OF DATA SUPPLIED TO THE CTC (IN REQUEST FOR NON-PASSENGER OPERATION ON CN LINE)

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

The following conclusions were drawn based on the test program and analysis carried out.

- An engineering evaluation of the preliminary test results of previous programs, together with analysis of the recommendations and requirements of CN Rail and the CTC authorities, has led to several modifications which have been incorporated into the Railbus design. The added features should improve the vehicle's serviceability, reliability, performance and measured level of passenger and driver comfort.

- The one major difficulty affecting the start of the test program was the unexpected amount of time and effort required to refinish the surface and mounting rims of the railbus wheels (nearly 150 man-hours). Special jigs were required to be fabricated and tooling holes added to the wheels to assure trueness (when assembled) and a proper surface profile.

- It is concluded that the operating rules, practices, and operating procedures proposed in this report, when implemented, will create a safe environment for the operation of the WCSS railbus on CN lines.

- The vehicle modifications to enable it to operate on rails have resulted in successful operations in terms of:

  - stability;
  - curving;
  - switching
  - braking; and
  - traction.

- Bearing life was concluded to be in the worst case at least 1000 hrs, which for the intended operation is adequate for approximately a year of service. It is concluded that regular inspection and maintenance will ensure safe operation.

- The vehicle as tested was considered not sufficiently reliable for a daily demonstration service in winter conditions, but improvements are possible to achieve this goal, particularly when combined with an aggressive maintenance plan. (See 9.2).

- The turntable installed in the vehicle proved to be unreliable and suffered one major failure. After rework and strengthening, operational tests at normal temperatures appeared to be satisfactory, but some signs of unequal lifting occurred at temperatures of -25°C.

- The main contributor to vehicle unreliability was the age and considerable prior accumulation of mileage as a road vehicle rather than the rail conversion.

- Emergency lighting and heater operation can be sustained for 24 hours in event of engine failure, but emergency heater output is marginal and should be improved. This increase in heat output would not impact on the 24 hour target.

- The degree of controllability of both braking and acceleration is extremely good by rail vehicle standards as both foot-operated controls have retained the bus feature of continuous variability. This enables the driver to stop wheelspin or sliding very quickly.

In summary it is concluded that the vehicle is suitable as a passenger demonstration vehicle for remote service railbus operation if a number of features found to be unreliable in daily use are upgraded and the recommendations below implemented.

9.2 RECOMMENDATIONS

Review of vehicle operations has led to the following recommendations to be noted for implementation before a winter demonstration service:

- The turntable hydraulic system to be reviewed and reworked to provide an equal lift/lowering capability under all load conditions and temperatures;

- The hydraulic fluid to be replaced from a low-temperature type to an arctic-type;

- The hydraulic winch requires modification to provide the required rotational rate;

- Improved rubber-mounted suspension supports be installed to dampen rail noise (wheel flats, rail joints, etc.) being transmitted to the passenger area;

- The maximum engine governed speed be lowered to 2600 rpm, transmission shift speed be lowered to 2350 rpm, and the differential ratio changed to accommodate an 80 kph vehicle speed at a maximum engine speed of 2600 rpm.

- The driver instrumentation panel be updated with back-light gauges, a calibrated transmission driven speedometer and also an engine driven tachometer should be included;

- The engine fan to be replaced from a steel-type to a nylon blade design (primarily for safety reasons);

- The fuel supply should have a water separator and fuel heater installed near the tank;

- The air supply should have an air-drier installed to remove moisture, oils and residues;
- Driver comforts to be added including an arm-rest, dash mounted grab-bar and a glare free paint finish over the windshield area; and
- Further trials be carried out in full winter conditions before passengers are carried, in order to eliminate any remaining problems not discovered during Fall weather conditions.
- An agressive maintenance and inspection procedure be followed during any passenger operation to maintain acceptable reliability and safety.
- A "train-rider" familiar with the vehicles design and operation be carried on any passenger demonstration service undertaken.
- Further development of a "Railbus specific" category of vehicle regulatory requirements be pursued, which would take into account the differences between remote service Railbus operation and conventional rail operation with locomotives and trains.

10.0 REFERENCES

1. "Design, Development and Testing of A Modified Flyer Bus as a Railbus" TP 6912E prepared by Winnipeg Coach Sales and Service for the Transportation Development Centre, August 1985.

2. "Tracking Ability Assessment of an Experimental Railbus Vehicle" TP 7344E prepared by Dynamic Science Ltd. for the Transportation Development Centre, March 1985.

3. "Plan For The Testing of the WCSS Railbus on the INCO Railway Line" TP 7130E prepared by TTL for the Transportation Development Centre, October 1985

4. "Technical and Regulation Requirements for Vehicle Acceptance on CN Railway Line", TTL Report No. 338-520-002, August 1985.

5. "Standard Gauge - Transportation Standard Practice" International Nickle Company Ltd.

6. "Test Plan for Testing of WCSS Railbus on INCO Railway Line", TTL Report No. 338-610-001, August 1985.

7. Uniform Code of Operating Rules (UCOR - 1962).

8. Current Timetable No. 27 Prairie Region (CNR 27 October 1985).

9. Safety Rules and Instructions - Revision (CNR September 1972).

10. General Operating Instructions - Revision (CNR June 1985).

11. Regulations for Track Units and Maintenance (CNR July 1985).

12. Meeting Minutes. Railbus Technical Advisory Committee. September 4 1985.

13. Railbus Programme. Request for Authorization to CTC submitted by TDC to secretary Mr. J. O'Hara. October 10 1985.

APPENDIX 1

PHOTOGRAPHIC RECORD OF TEST PROGRAM

APPENDIX 2

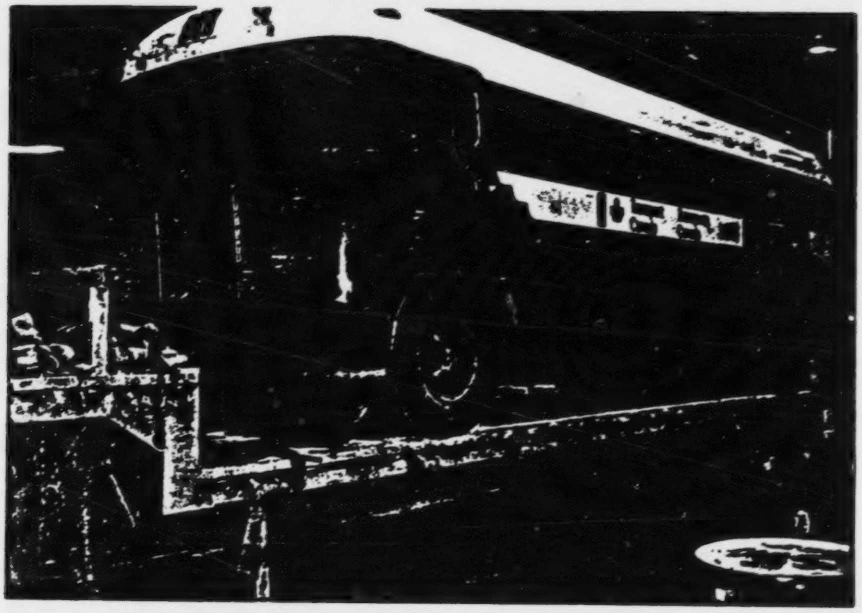
"WCSS RAILBUS EVALUATION TESTING ON INCO RAILWAY LINE"

- TEST REPORT

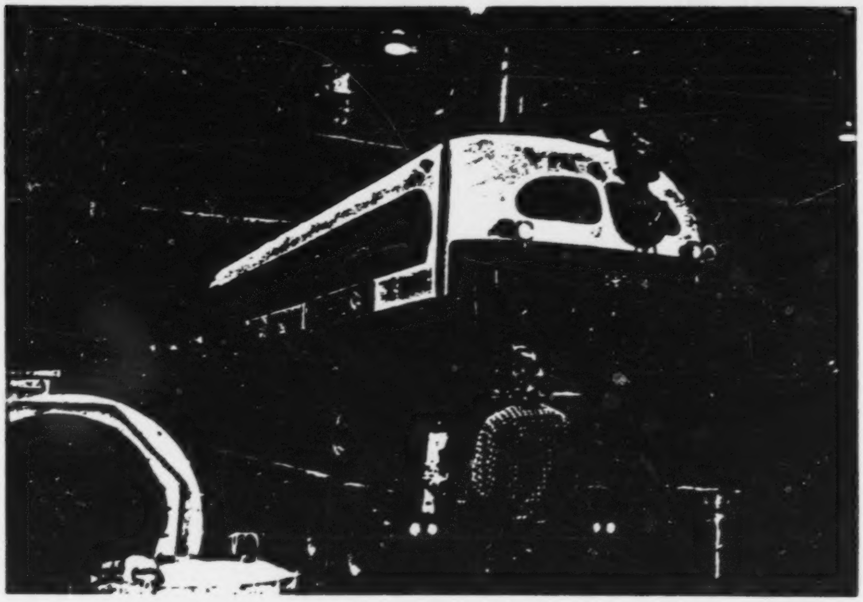
THOMPSON
VIA
85 8 1

THOMPSON'S VIA STATION

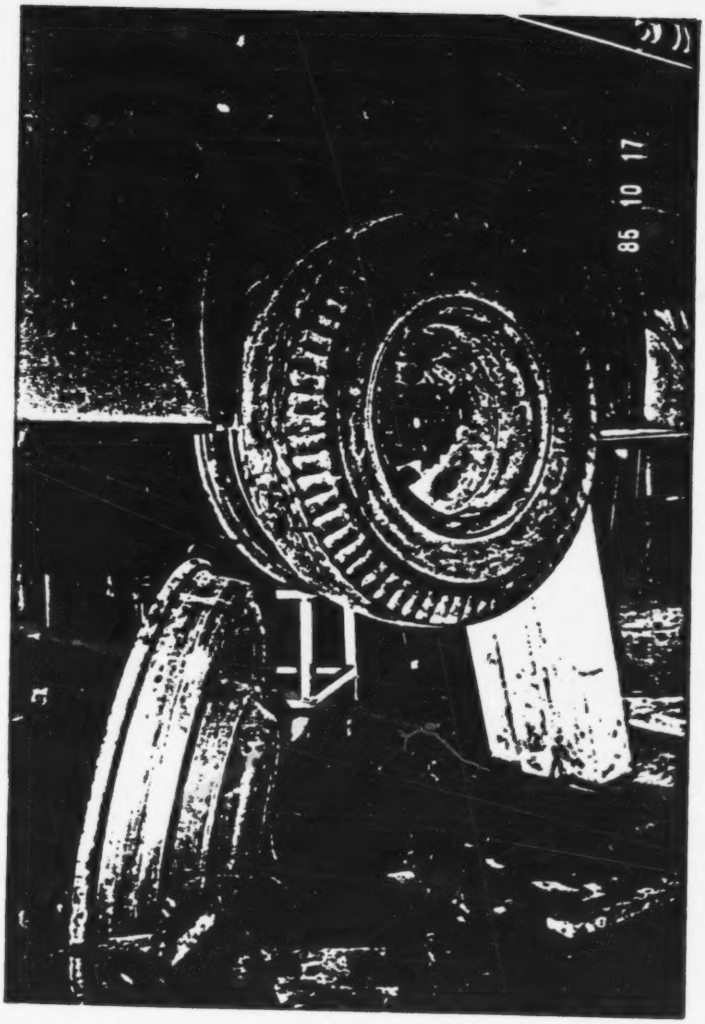
INCO-THOMPSON, MANITOBA



WCSS RAILBUS ON FLATBED TRUCK



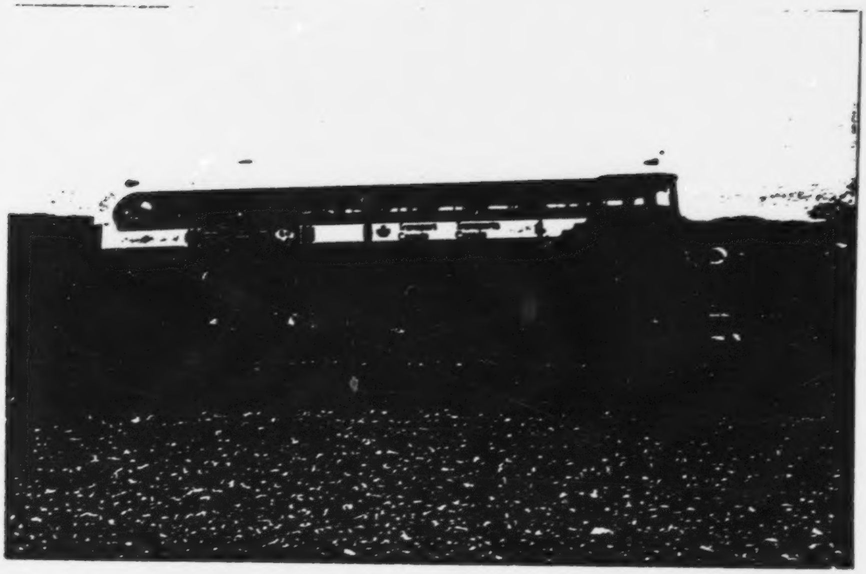
OVER-HEAD CRANE LIFTING VEHICLE OFF TRUCK



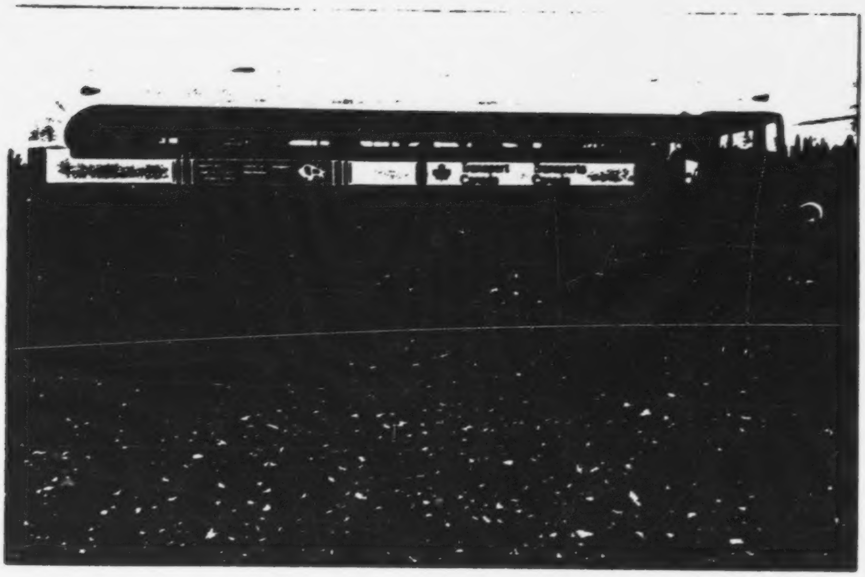
DETAIL OF ROAD-TO-RAIL

WHEEL CONVERSION

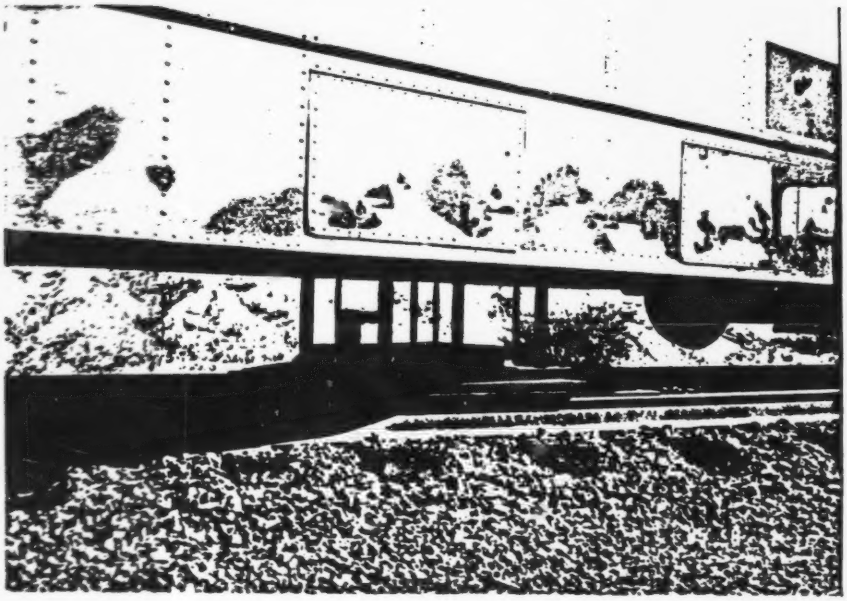
FRONTAL VIEW OF RAILBUS



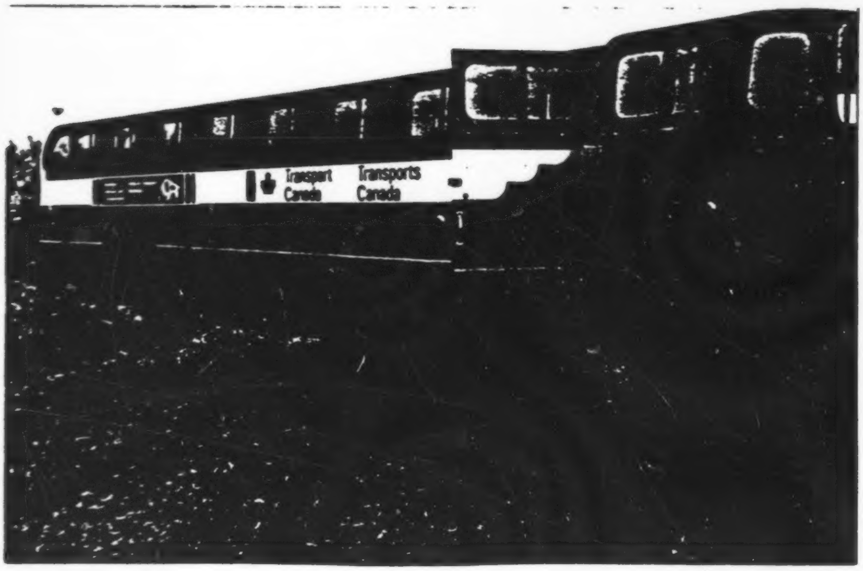
TURNTABLE OPERATION-UNEQUAL LIFT



TURNTABLE FULLY EXTENDED



DETAIL OF TURNTABLE AND LIFT ASSEMBLY


Transport Canada
Transports Canada

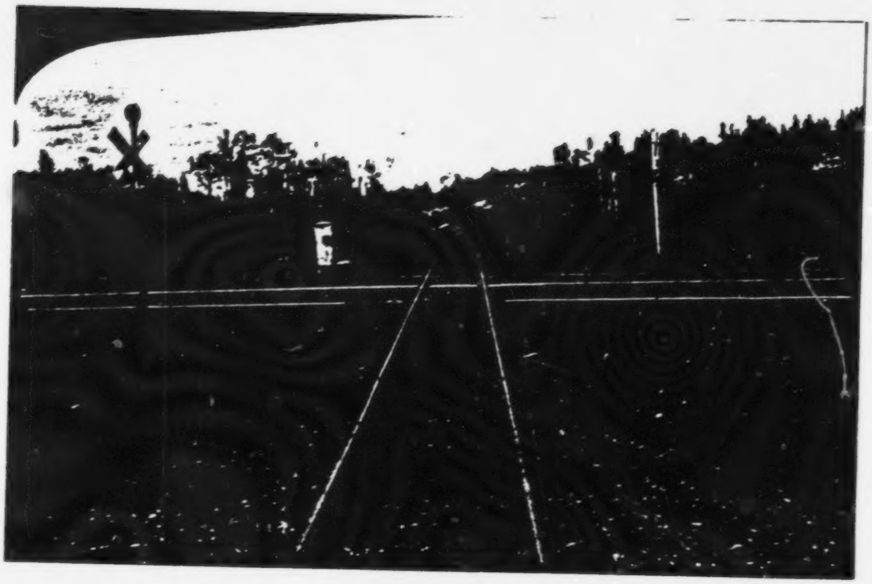
RAILBUS TURNING ON INCO TRACK

VEHICLE CLEARANCE AT TRACK LEVEL

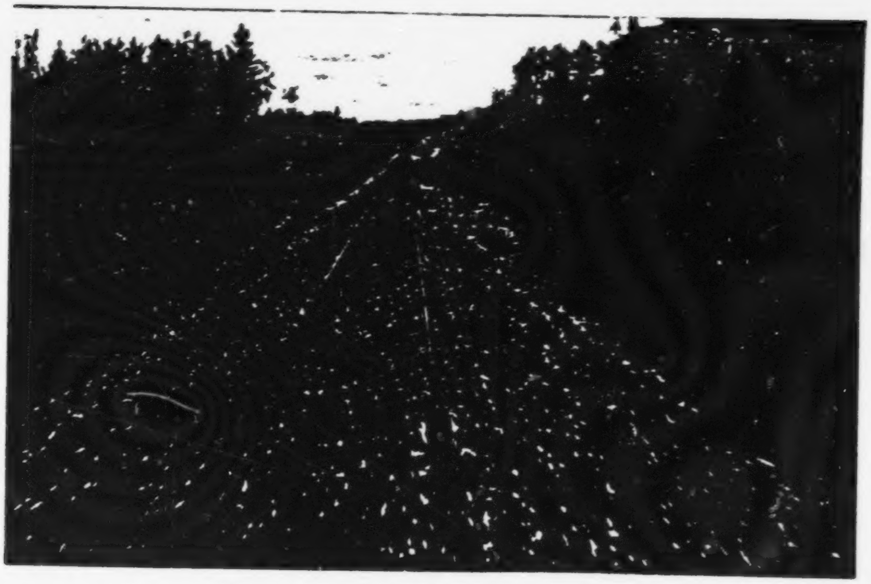
PRIOR TO TESTS

INCO'S SWITCH YARD IN THOMPSON

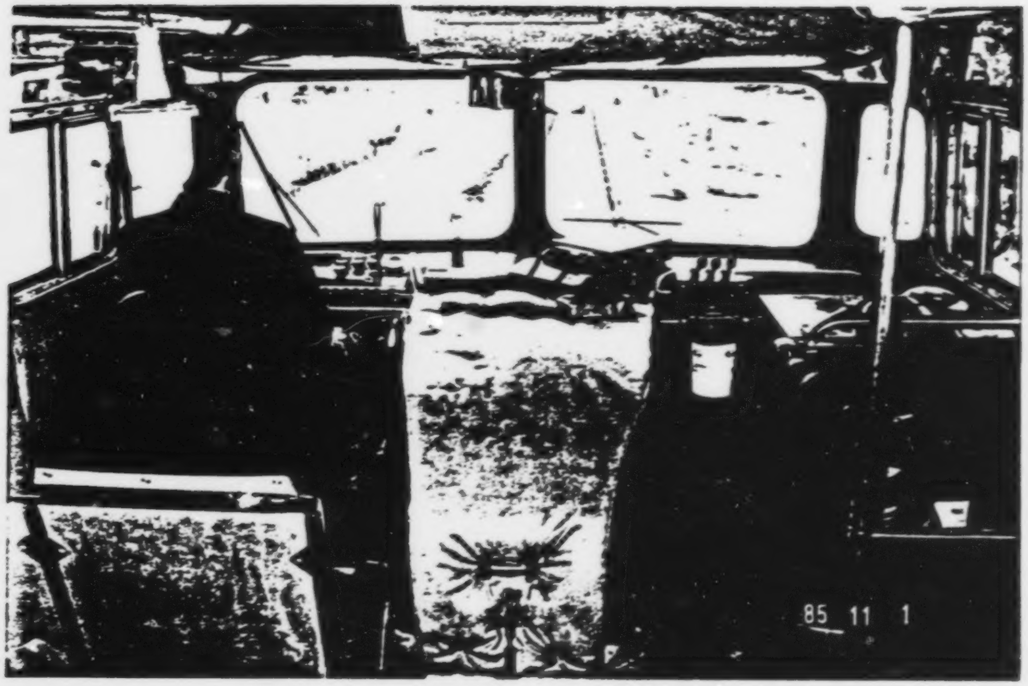
INCO'S TRACK OUTSIDE THOMPSON



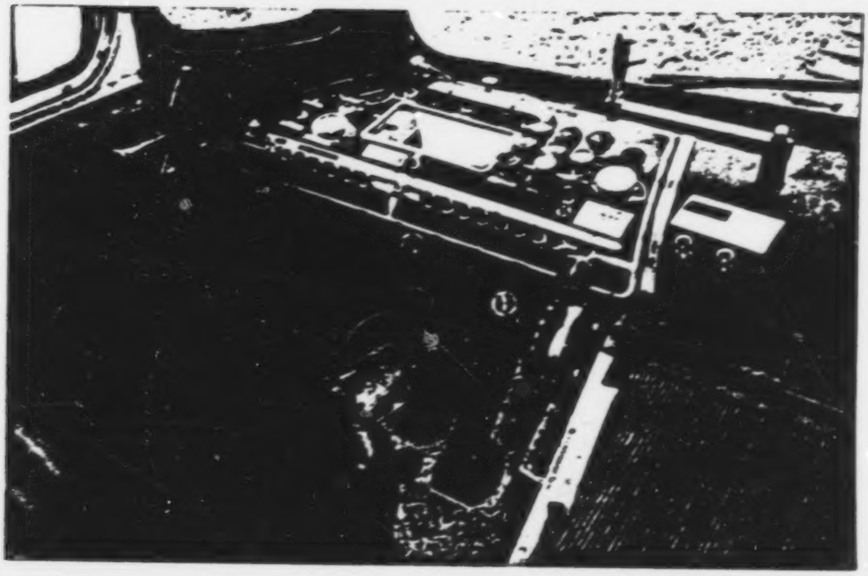
PUBLIC CROSSING ON INCO TRACK



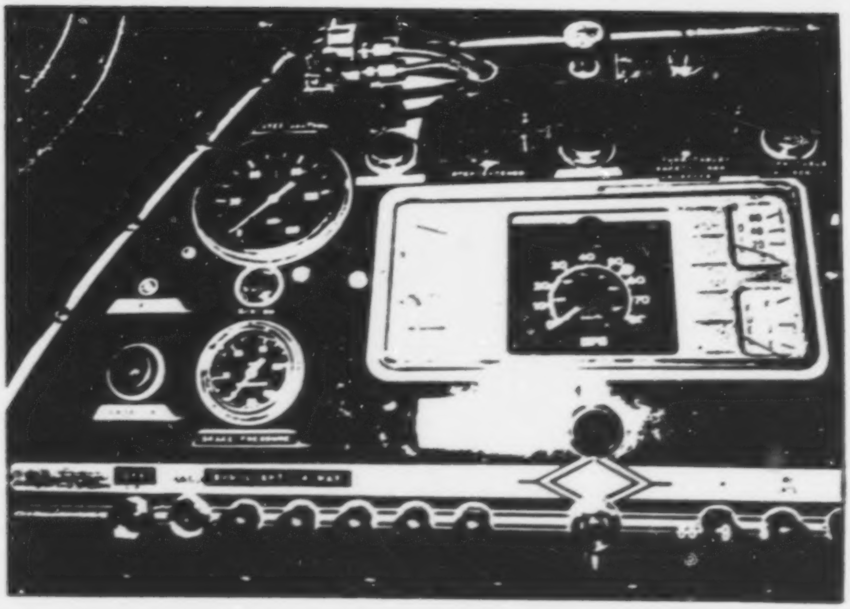
TEST SITE - MILE LOCATION 16-18



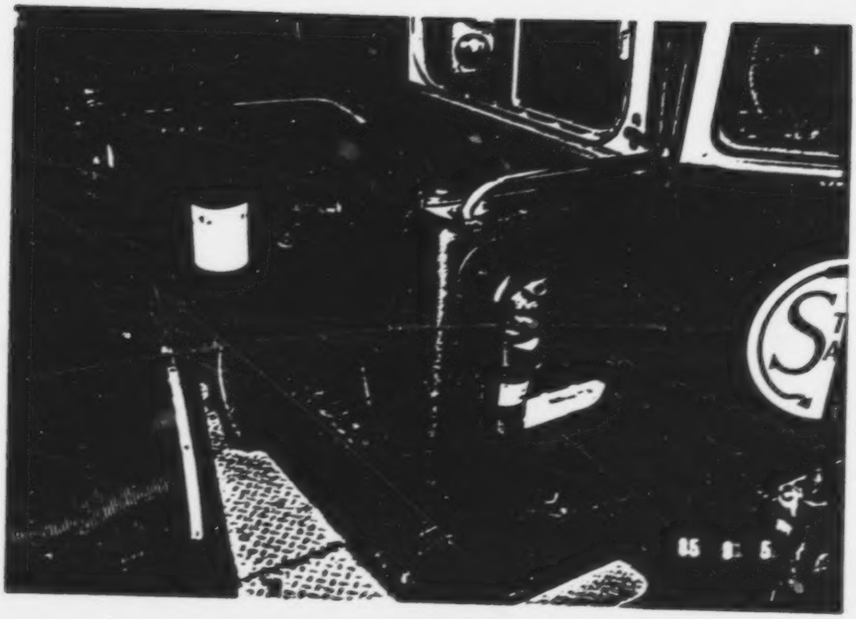
RAILBUS INTERIOR - ENGINE HOOD COVER



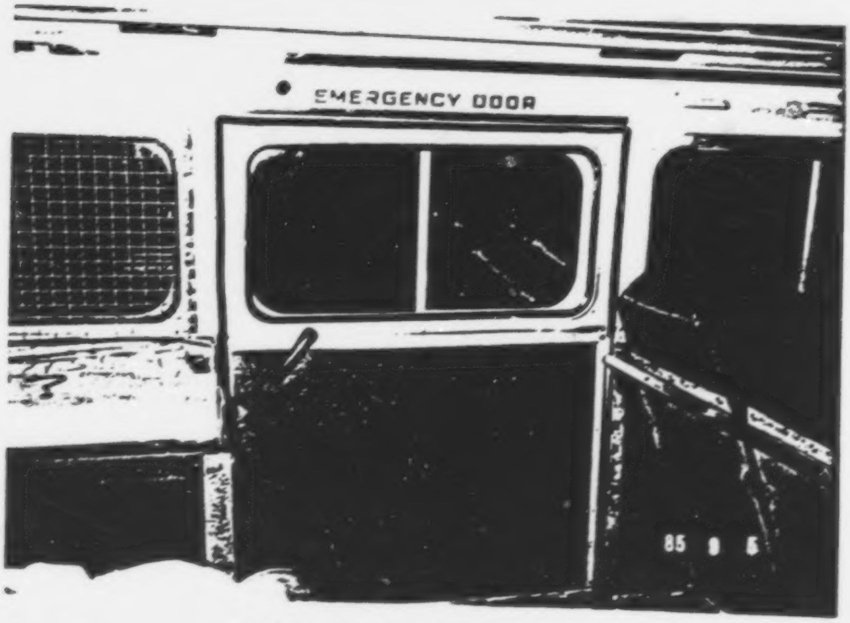
DRIVER CONTROLS - DEADMAN FOOT SWITCH



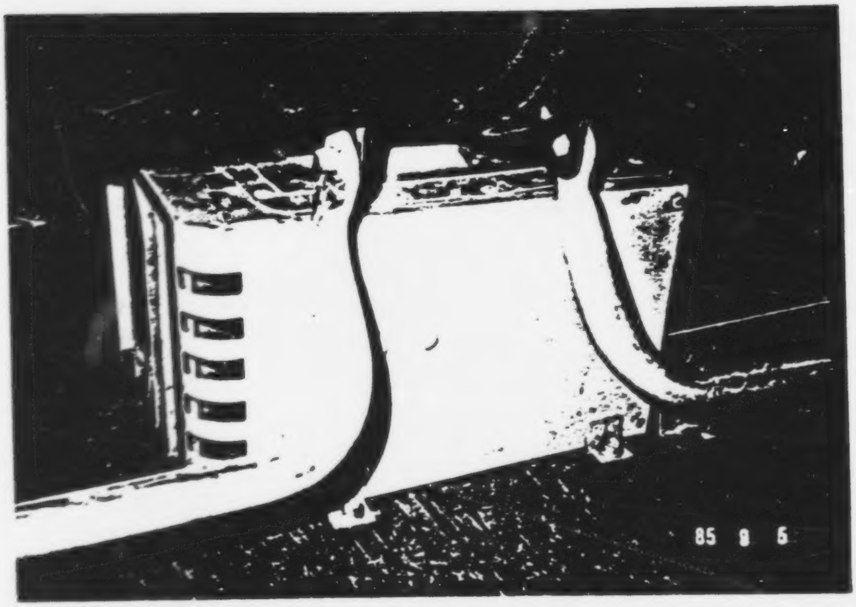
RAILBUS DASH PANEL



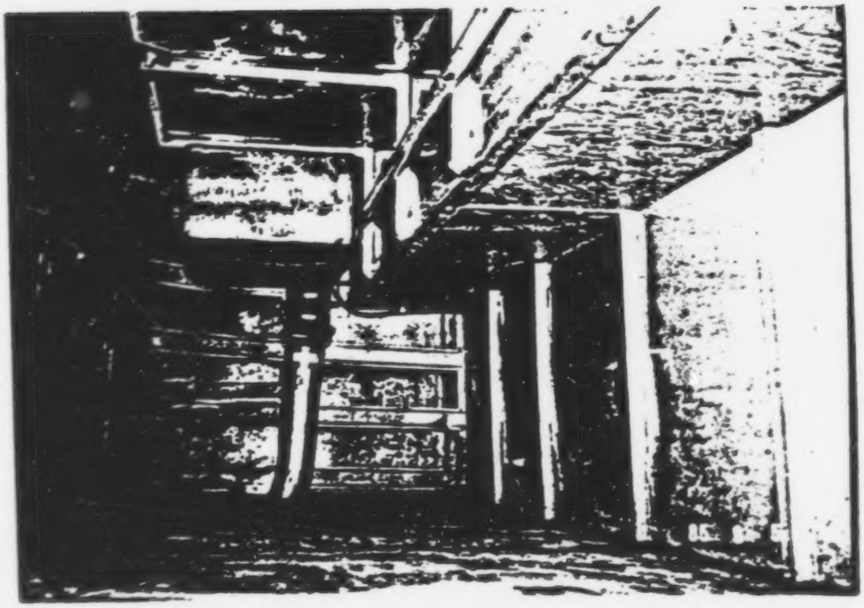
HYDRAULIC RESERVOIR AND SELECTOR VALVE


EMERGENCY DOOR
85 9 5

DOOR AT BACK OF RAILBUS

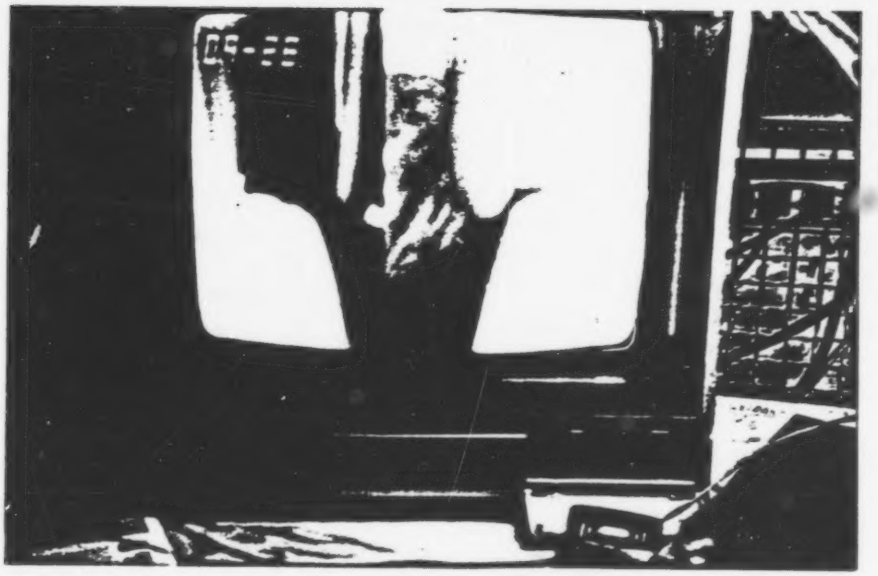


INTER UNDER-SEAT HEATER



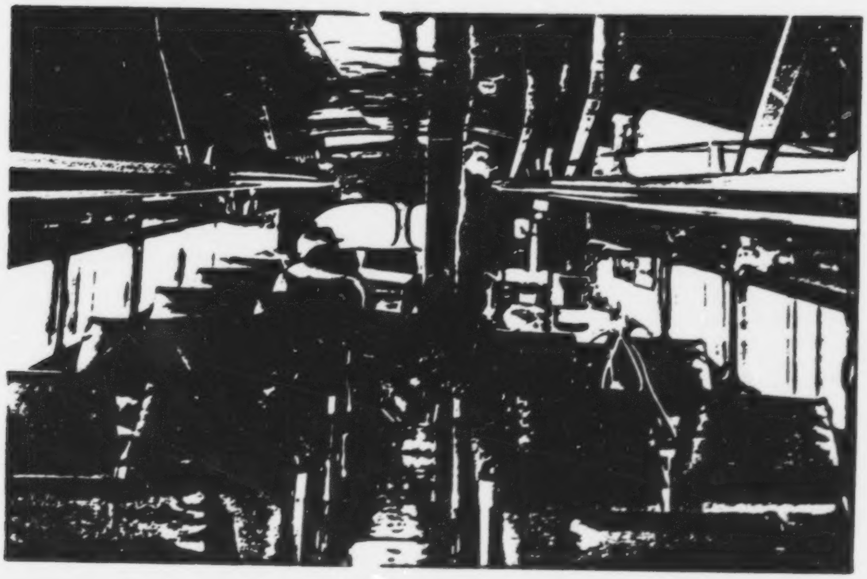
WASTE HOLDING TANK AT REAR OF RAILBUS

TEST EQUIPMENT INSTALLED ON RAILBUS



VIDEO MONITOR SHOWING WHEEL-TO-RAIL

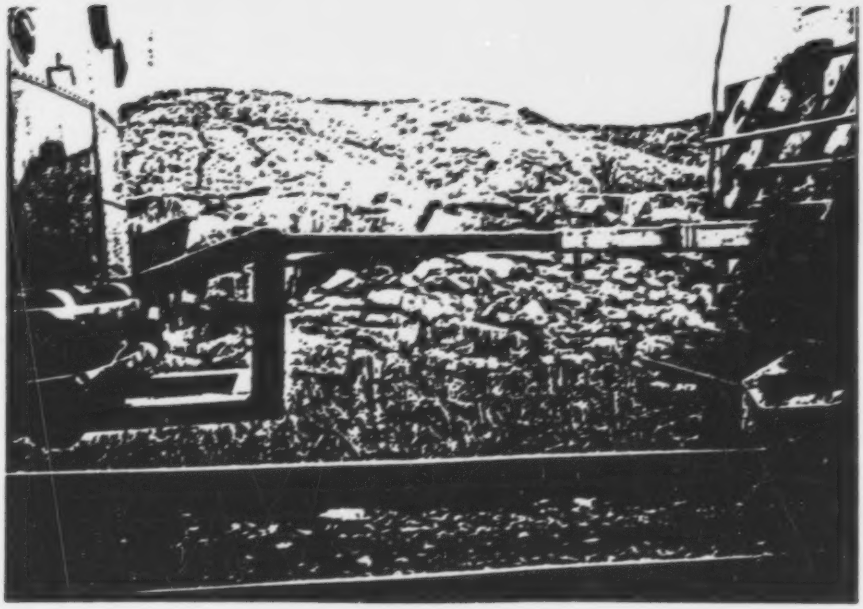
INTERFACE



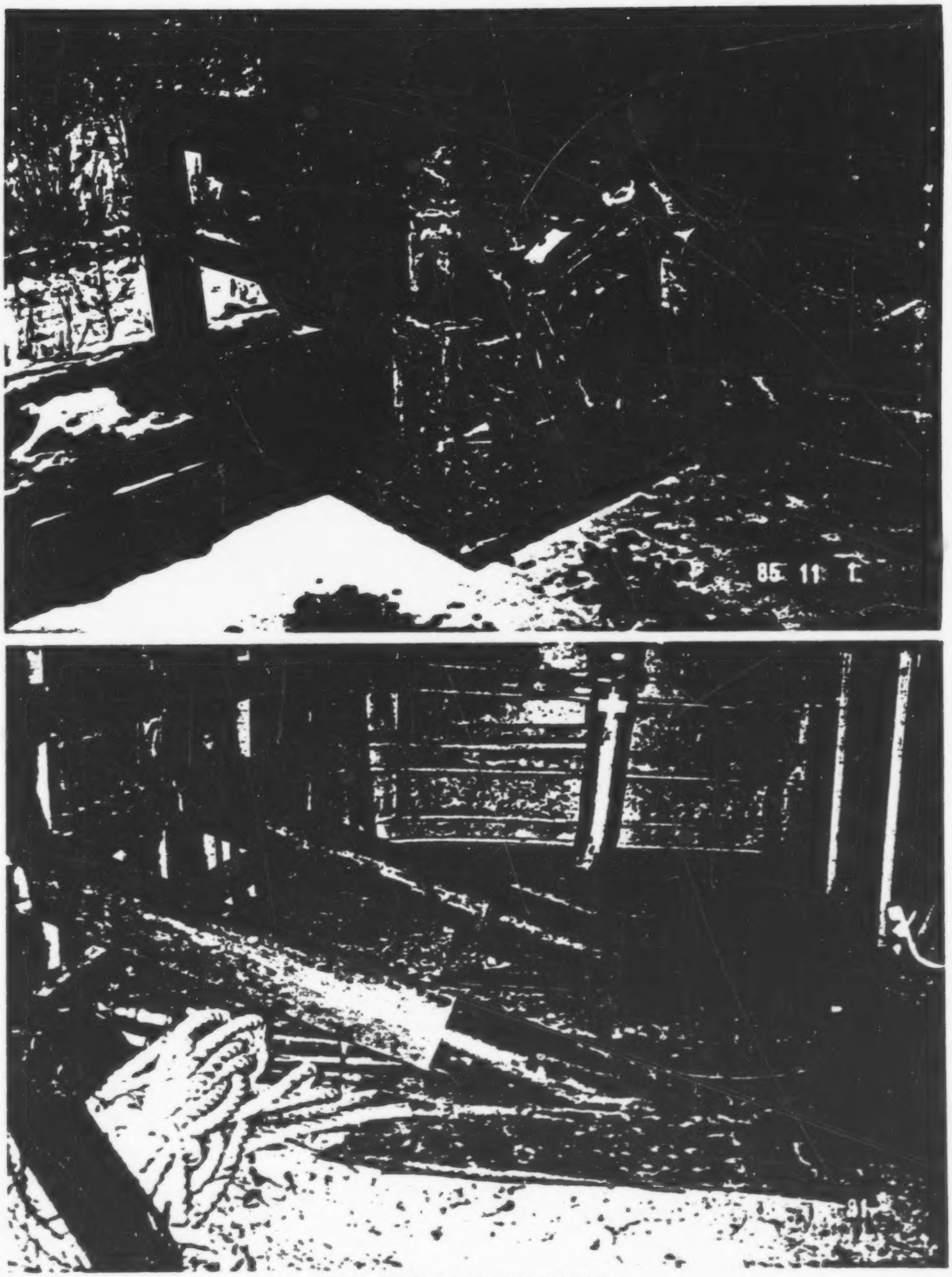
TEST TECHNICIAN MONITORING VEHICLE PERFORMANCE

VIDEO CAMERAS MOUNTED BEHIND REAR AXLE

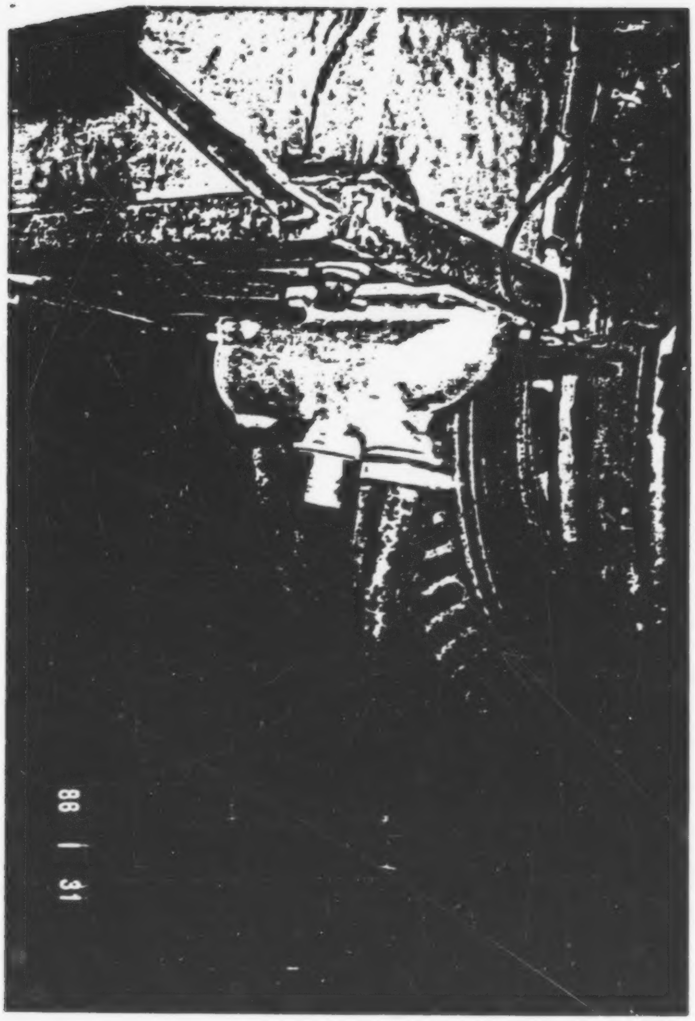
RAILBUS TOWED AT FRONT



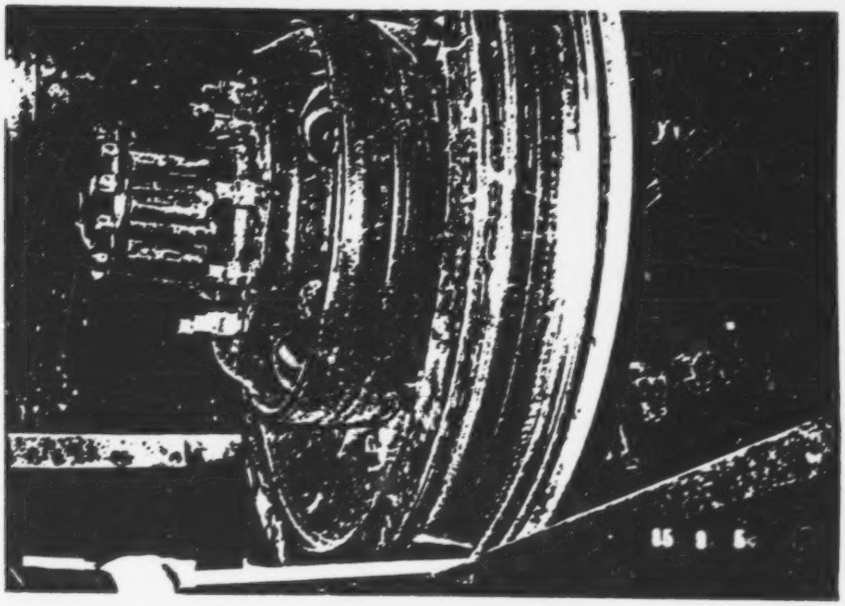
RAILBUS TOWED AT REAR



EXTENSION/REINFORCEMENT
FRAME AND POWER WINCH
INSTALLED AT REAR OF RAILBUS

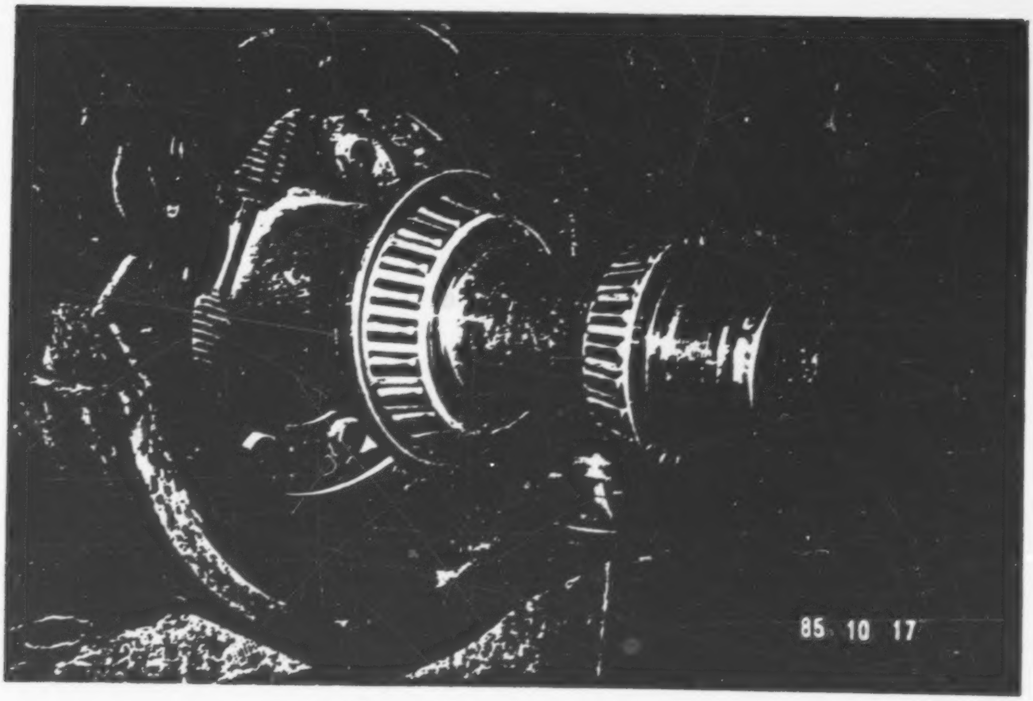


WHEEL SANDERS INSTALLED IN FRONT OF REAR AXLE



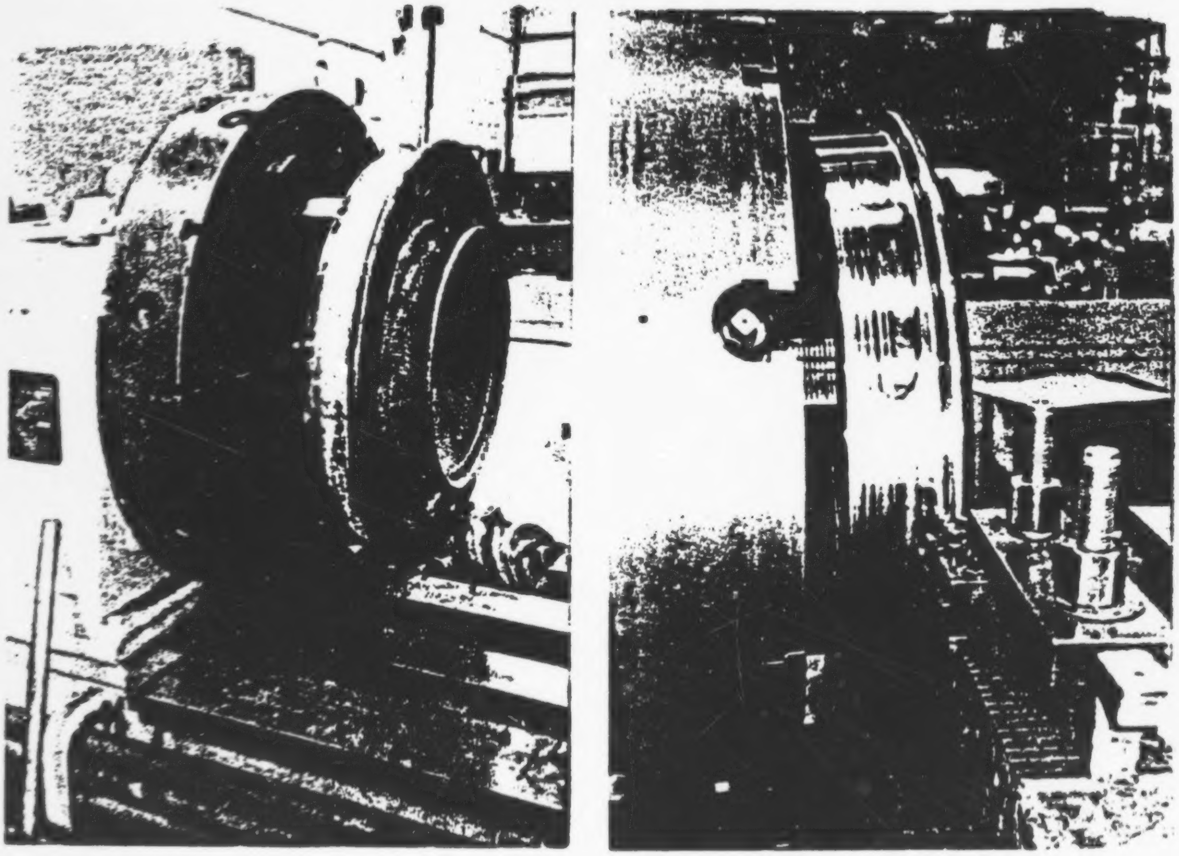
85 8 5

WHEEL ASSEMBLY ON VEHICLE



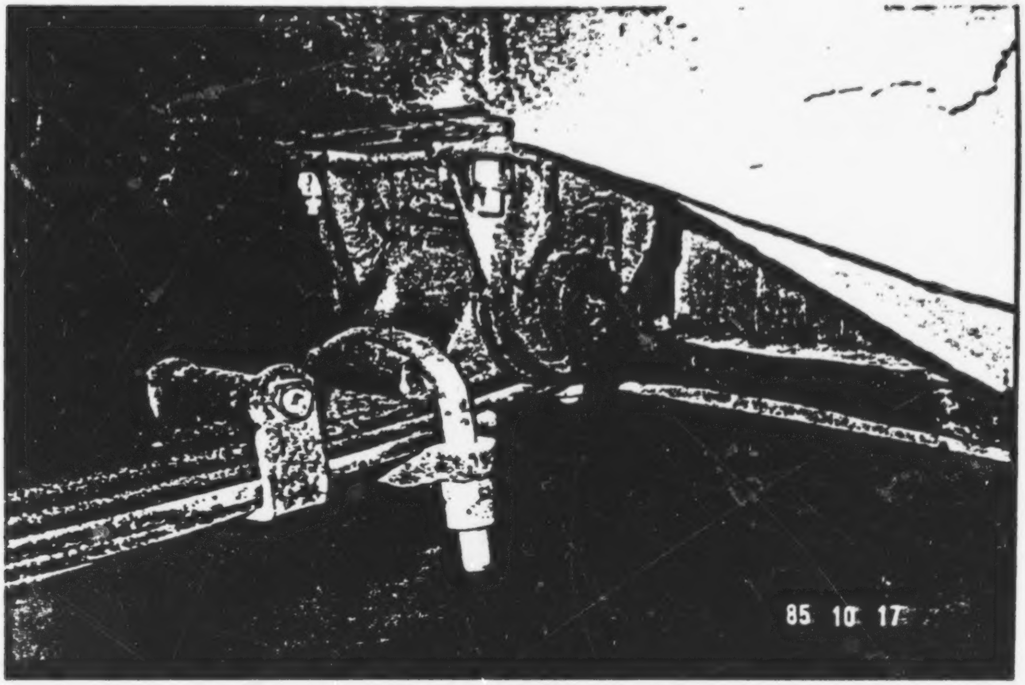
85 10 17

WHEEL BEARING INSPECTION

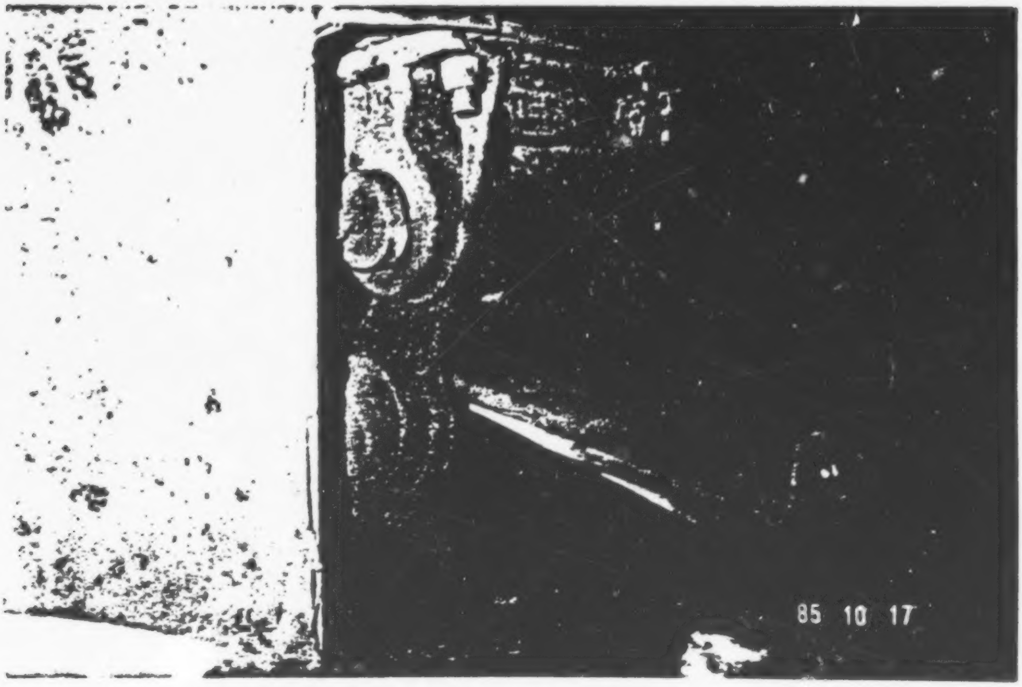


WHEEL SURFACES INSPECTED AND MACHINED

PRIOR TO TESTS

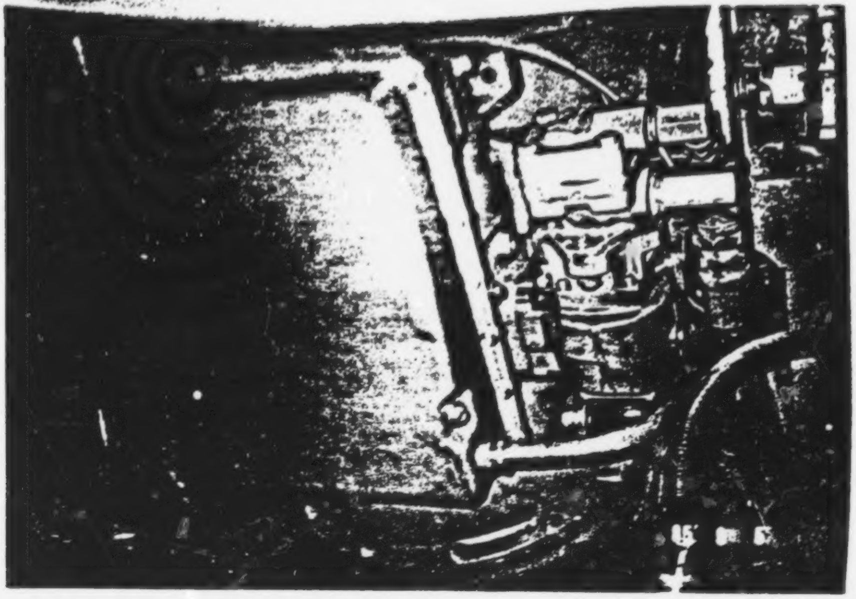


AXLE LEAF-SPRING

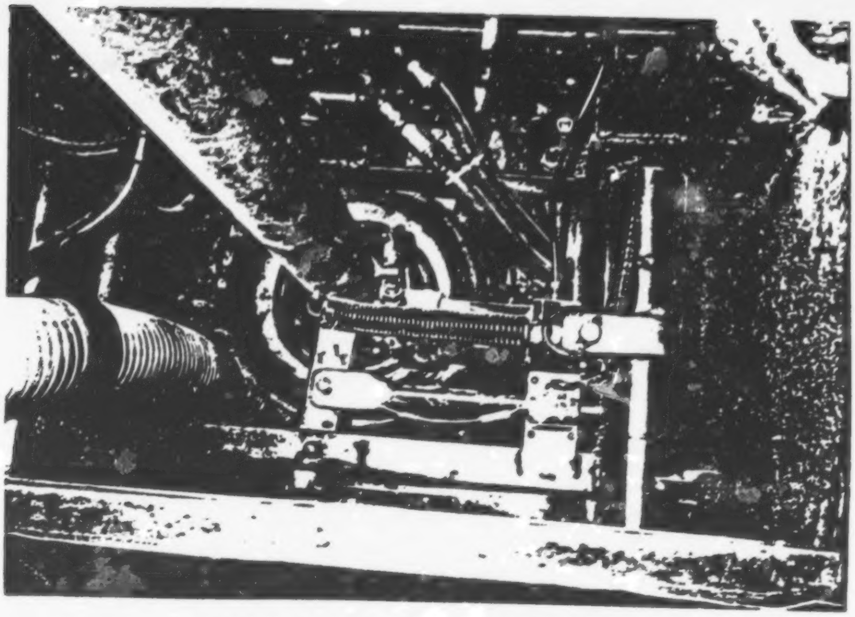


FRONT AND REAR MOUNTS OF LEAF-SPRING

- NOTE RUBBER ISOLATION PADS



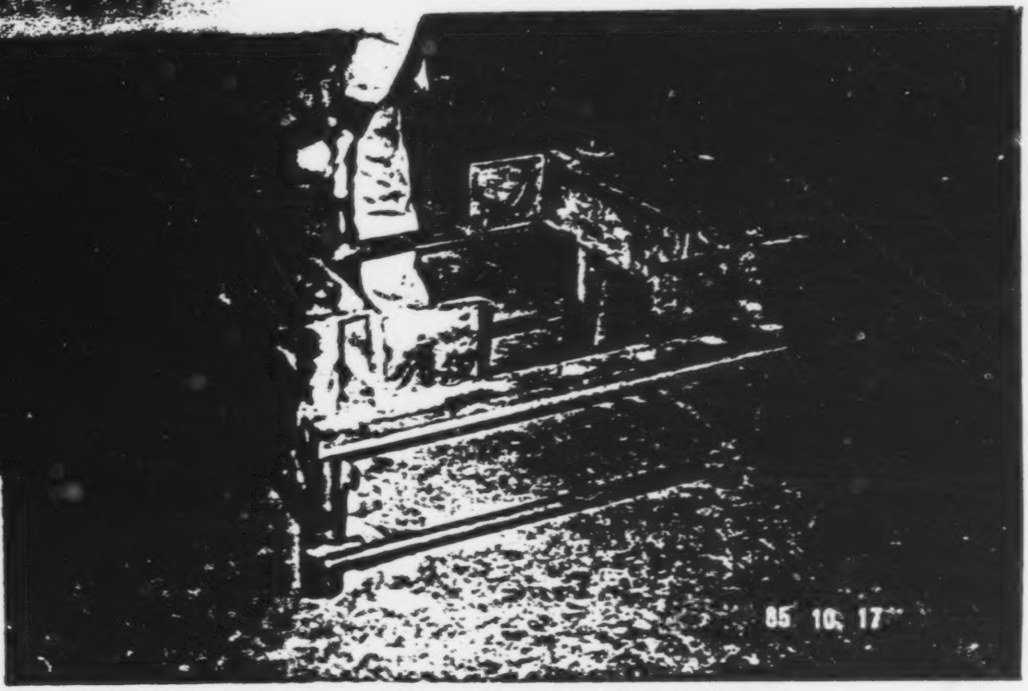
BOTTOM VIEW OF TRANSMISSION AND HYDRAULIC PUMP



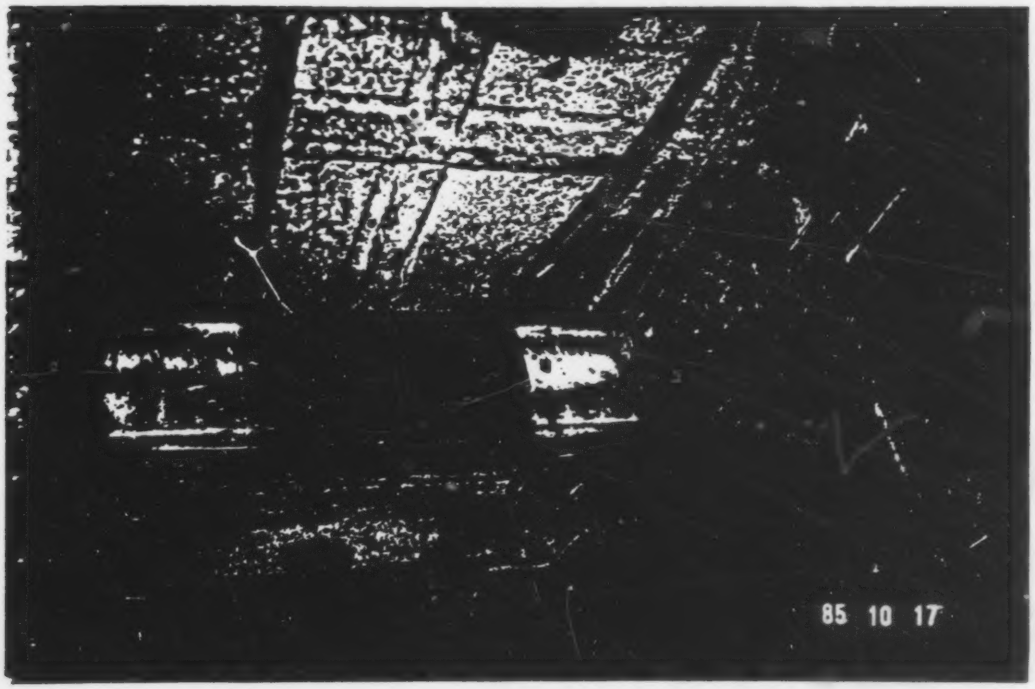
DRIVELINE-BRAKE OVER TURNTABLE

RELOCATED PARKING-BRAKE ON

END OF TRANSMISSION

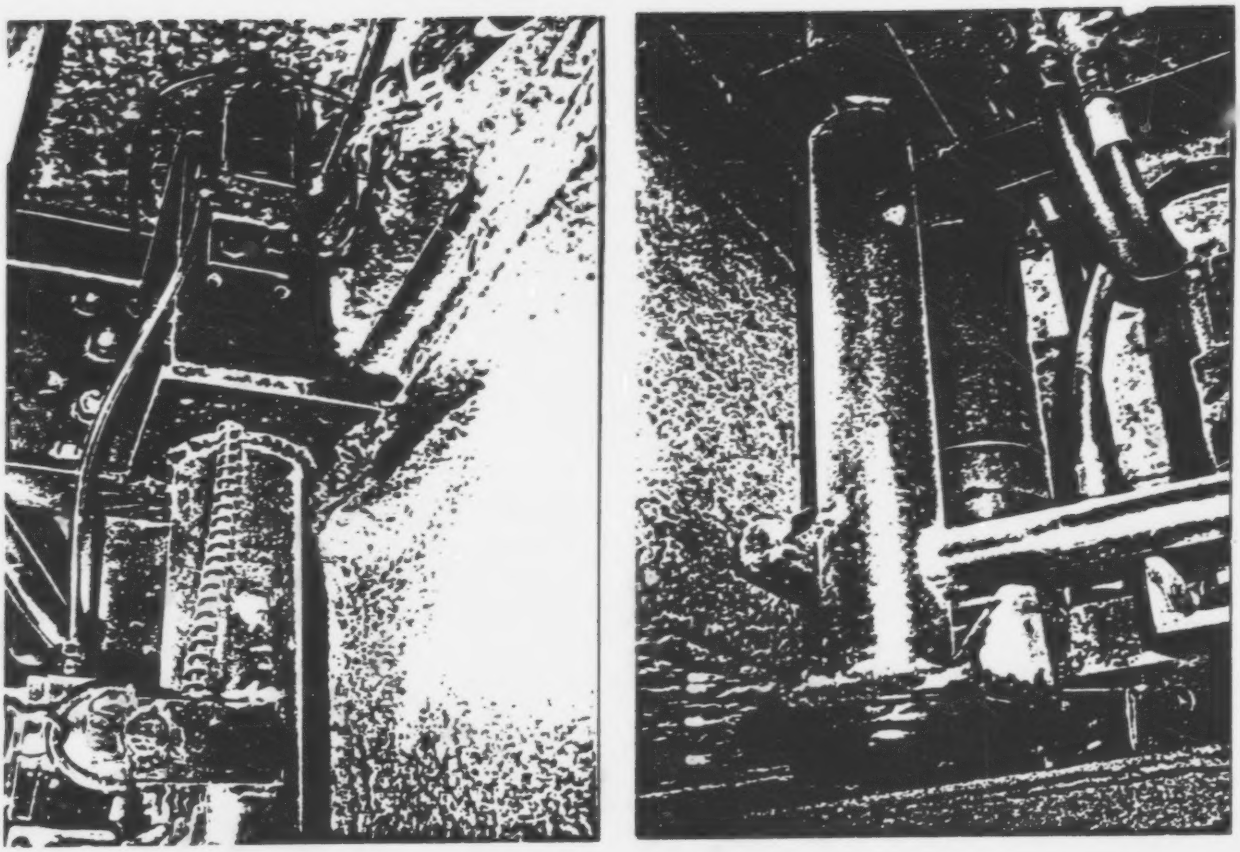


TURNTABLE GUIDE ASSEMBLY - BODY MOUNTED

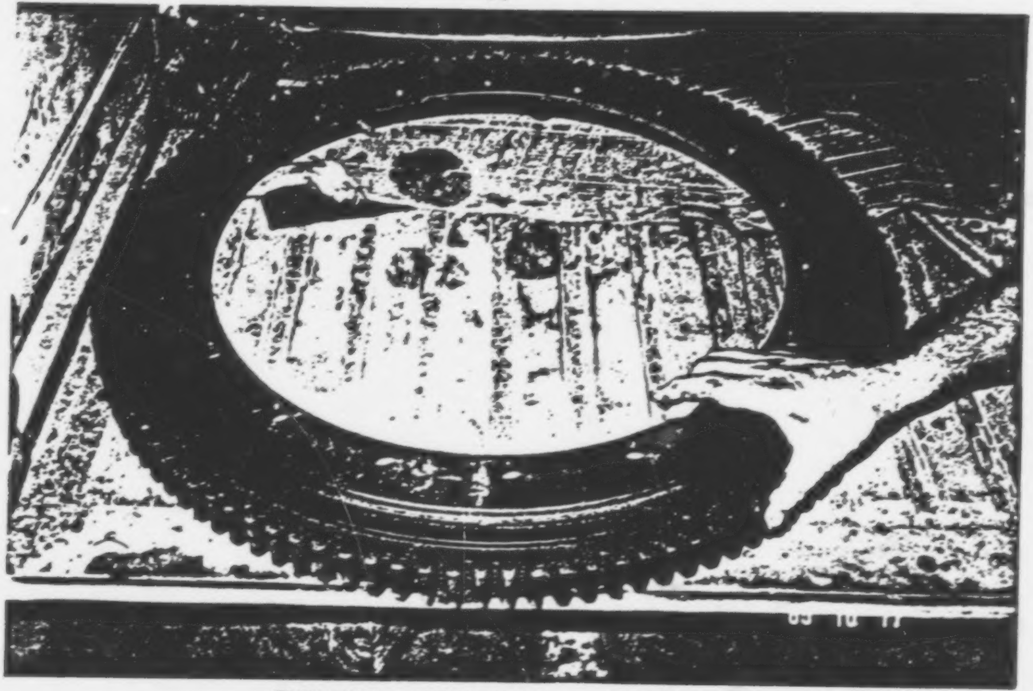


RAILBUS UNDER-FRAME FOR MOUNTING

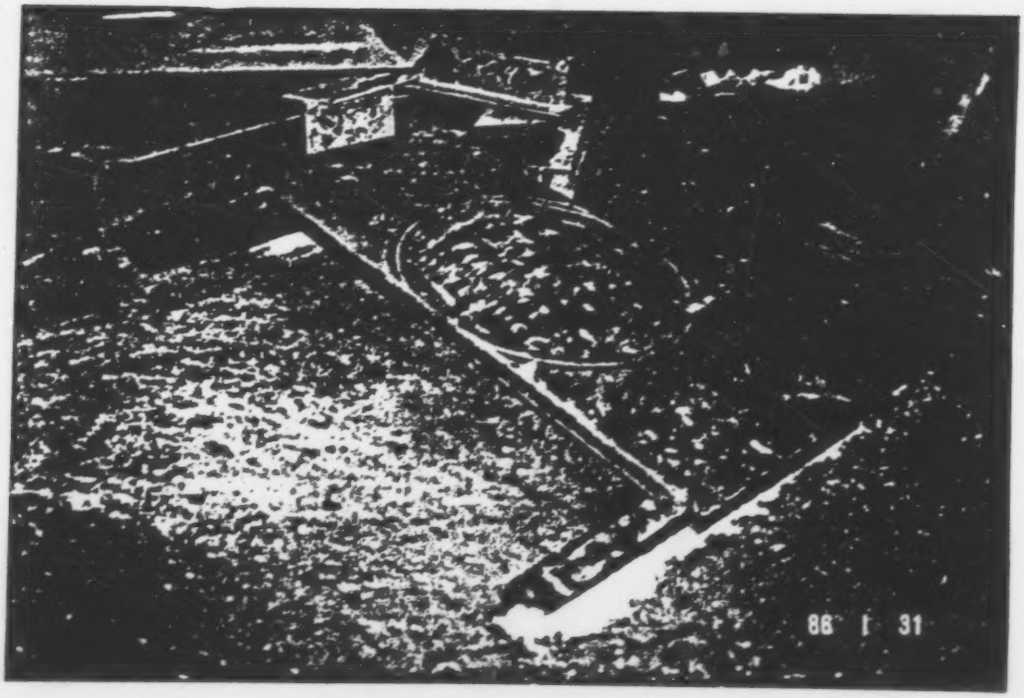
GUIDE ASSEMBLY



TURNTABLE GUIDE AND LIFT ASSEMBLY



TURNTABLE RING GEAR AND BEARING



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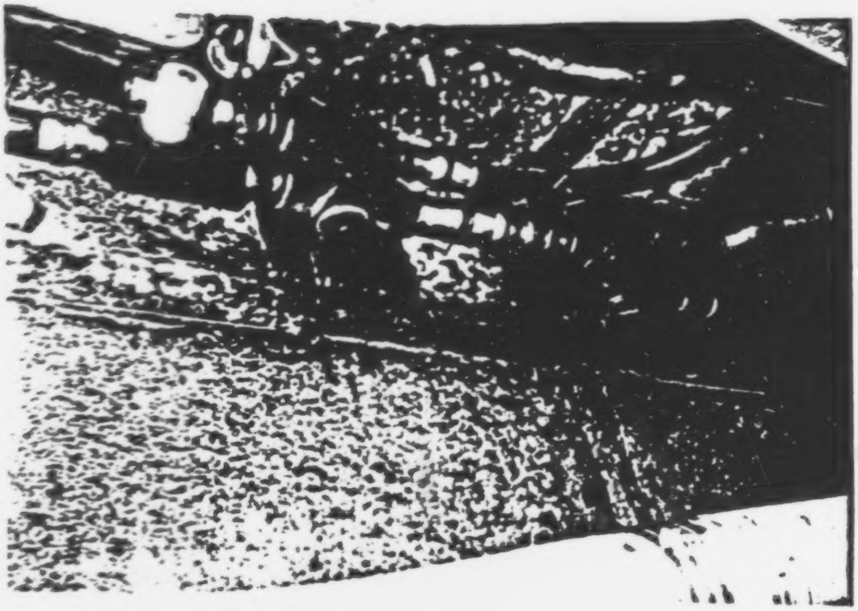
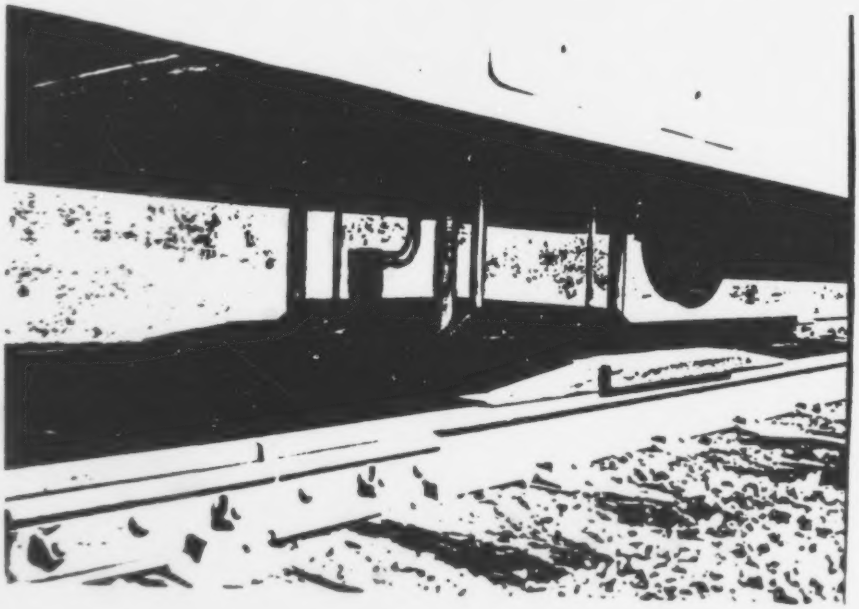
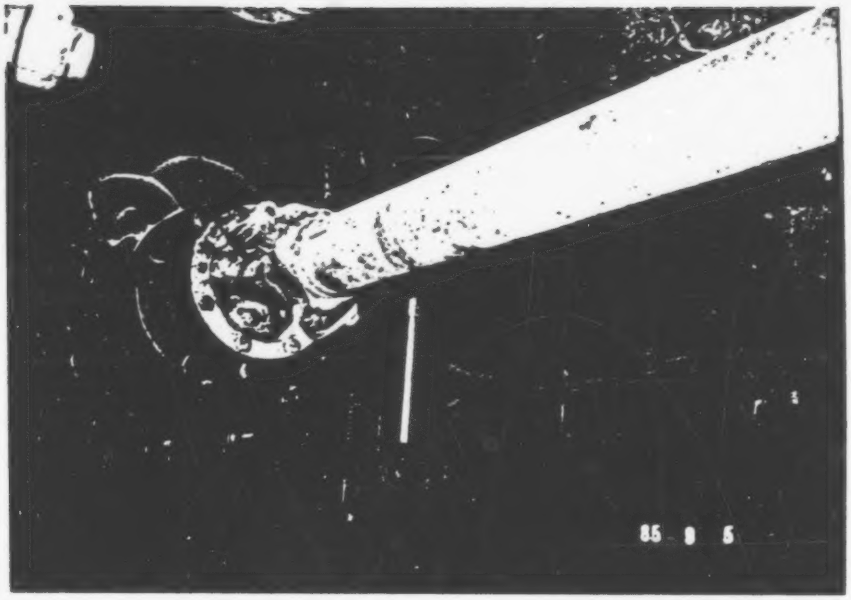
TURNTABLE TRACK SUPPORT



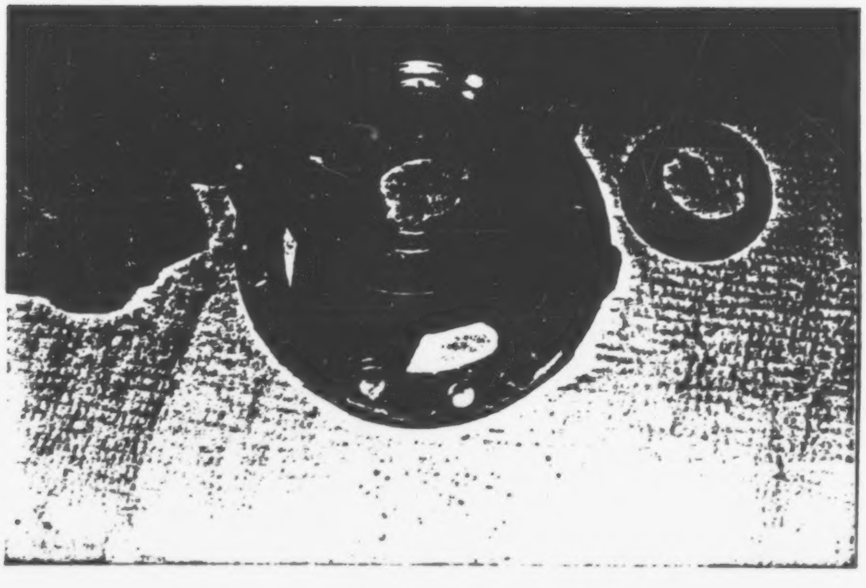
TURNTABLE LIFT CONTROL - FLOW DIVIDER



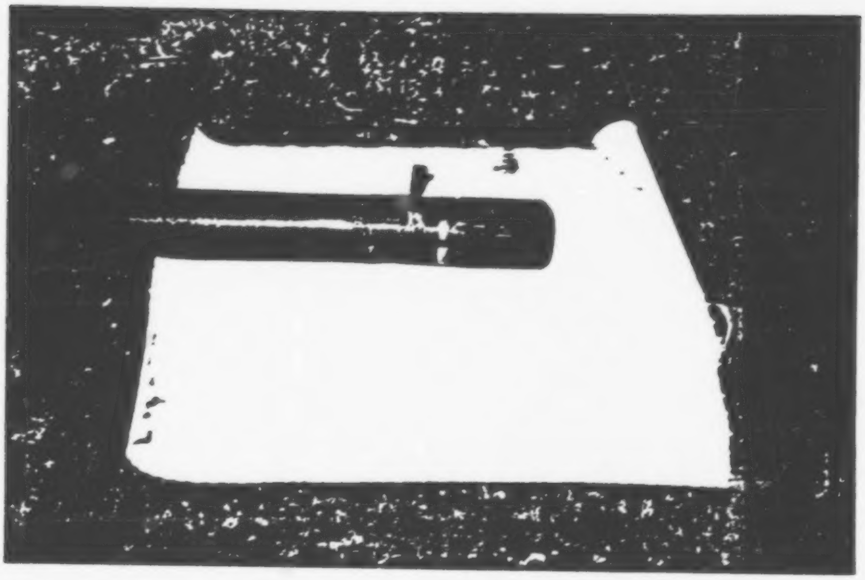
HYDRAULIC MOTOR ON TURNTABLE



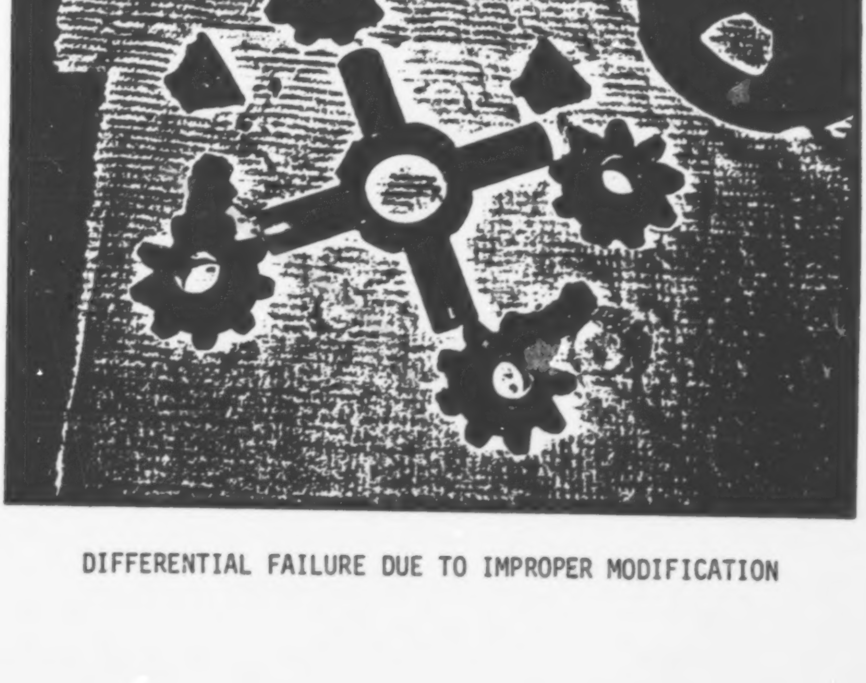
DRIVE-LINE TO DIFFERENTIAL



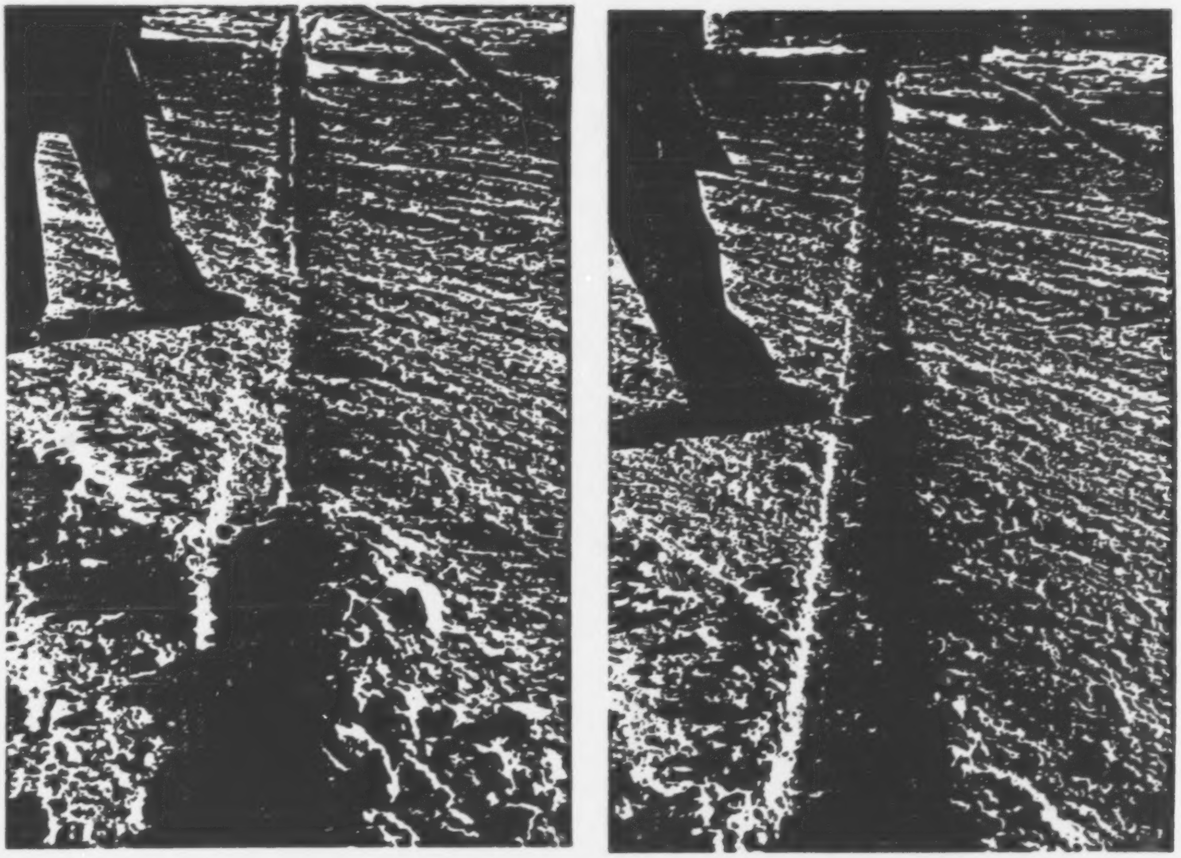
FAILED BEARING SUPPORT IN DIFFERENTIAL



DAMAGED AXLE DRIVE-SHAFT

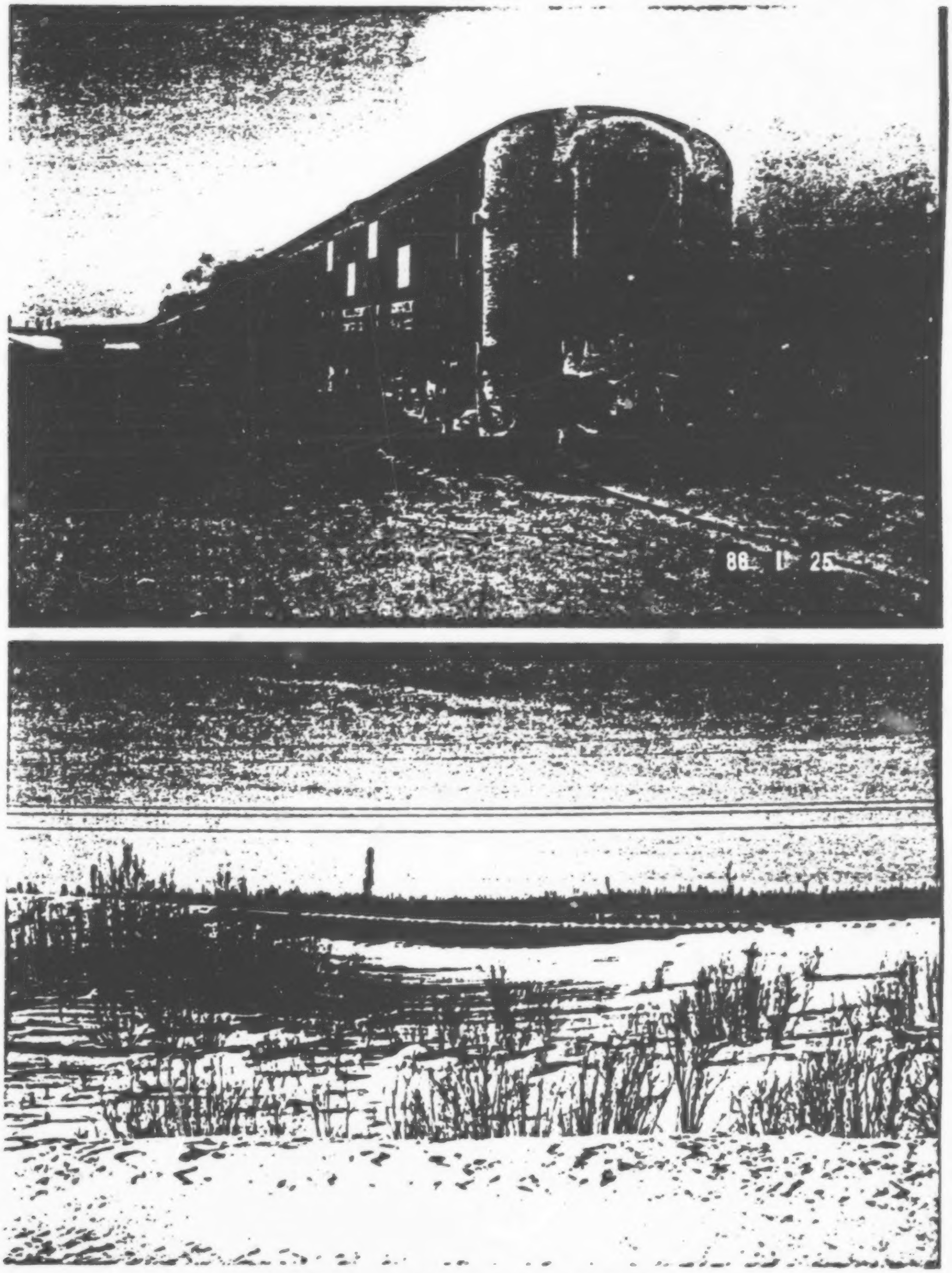


DIFFERENTIAL FAILURE DUE TO IMPROPER MODIFICATION



TRACKS BEFORE AND AFTER RAILBUS CROSSING

PRIOR TO WINTER TESTING



WINTER CONDITIONS IN THOMPSON

ON CN AND INCO RAIL LINES

UTDC Research & Development Ltd.

Project	**Title**	**Report No** 338-610-002		
		Date 85.12.12	**Issue** 1	**Page** i of iv
Railbus	Test Report	**By** H.R.S.	**Appd**	

WCSS RAILBUS

EVALUATION TESTING ON INCO RAILWAY LINE

Report No.: 338-610-002

Issue No.: 1

Copy No.:

Originator

Project Engineer

Project Manager

Date: Jan 16/86

Date: Feb 20/86

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SUMMARY

Various design features of the WCSS Railbus were tested during operational trials conducted on the INCO Railway Line. This report summarizes the findings observed by on-site TTL test personnel and in several cases suggests methods by which further improvements may be used to improve the vehicle's performance and reliability.

This report follows a standard format used by TTL, which is sufficiently detailed in the manner which describes the tests conducted. Individual test results which make up the report are subjected to self-contained test reports and include the procedure followed, site and vehicle status and a review of observations recorded.

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1.0 PURPOSE

The purpose of this report is to summarize the results of the tests conducted on the WCSS Railbus. Test measurements and data recorded were determined through the procedures described in TTL Report No. 338-610-001, "Test Plan For Testing Of The WCSS Railbus On INCO Railway Line" (Ref. 1).

2.0 METHODOLOGY

Tests were conducted on the INCO Railway Line during the months of September to November 1985. Prior to the commencement of the test trials, the vehicle was assessed, inspected and reworked in the areas outlined in TTL Reports No. 338-620-002, "Vehicle Inspection and Assessment" (Ref. 2), and No. 338-620-001, "Vehicle Preparation" (Ref. 3).

The test program was divided into two phases:

- Tests to be conducted prior to the mileage accumulation;
- Tests to be conducted following a mileage accumulation of 3,000 km.

Several test requirements specified the vehicle performance to be reviewed in a comparative manner and at various track speeds.

For those test requirements (i.e.: noise, ride quality, stability, etc.), a relatively level tangent track section was selected as the base test site - INCO Mile No. 16 to 18 was to be used.

The main switch yard outside INCO's production and maintenance facilities in Thompson was selected as the alternate test site where vehicle behaviour through various track curves and switch types would be monitored.

The majority of tests were conducted prior to the extensive vehicle mile accumulations exercise. Preliminary tests were also made for an unladen vehicle configuration.

Following the accumulation of nearly 3,000 km of track experience, the vehicle was modified as outlined in TTL Report No. 338-640-002 "Vehicle Modifications" (Ref. 4). Further tests were conducted including those for the loaded vehicle configuration.

Daily observations were recorded in the vehicle log book and data sheets prepared summarizing results of the various test measurements and procedures.

The following sections of this report were prepared as self-contained test reports. A summary of results obtained including recommendations is included at the end of the report.

3.0 VEHICLE NOISE

3.1 TEST OBJECTIVE

To measure the onboard and wayside noise levels generated by the railbus while operating at various track speeds.

3.2 TEST APPROACH

Measurements were taken at various railbus operational speeds and readings compared to established commercially acceptable sound level averages. Modifications were to be made to reduce the measured onboard noise level if it was determined that the railbus was unsuitable for a passenger service demonstration.

3.3 INSTRUMENTATION AND EQUIPMENT

Noise measurements were recorded from a hand held sound level meter manufactured by General Radio (USA). The meter was calibrated by the TTL test personnel using a certified sound level calibrator.

3.4 TEST SET UP

3.4.1 Onboard

The test was set up by dividing and marking the vehicle interior into five zones of equal size, each approximately 2.0 m (78 in) in length. The test was conducted on the INCO Railway Line within the designated test area between mile markings 16 and 18. The aisleway was kept clear.

3.4.2 Wayside

The test was set up by standing with the sound meter at the designated distance of 15 m and holding the instrument at approximately 1.5 m above the running rail.

An open track area was selected within the test zone to reduce the possibility of sound reflection (echo) from affecting the results.

3.5 TEST PROCEDURES

3.5.1 Onboard Noise

The initial test was conducted prior to the mileage accumulation exercise.

The railbus was driven to the test track area of the INCO Railway Line (mile 16). The vehicle was brought to an operating cruise speed of 32 kph (20 mph) and the speed maintained while sound level readings were taken in each of the five zones.

Sound level measurements were read from the A-scale and samples taken during 10 second intervals. The meter was held at chest level in an upright position. Average and peak dB(A) readings were recorded as well as vehicle direction.

Following the completion of the sound measurements at the speed indicated, the railbus was driven to the end of the test track (mile 19) and the vehicle was turned 180°. The procedure was repeated to measure onboard sound levels in the opposite direction and at the same operating speed.

Having completed the noise level measurements for the opposite direction, the railbus was turned 180° and the procedures repeated for vehicle cruise speeds including 48 kph (30 mph), 64 kph (40 mph) and the predetermined maximum safe operating speed of 72 kph (45 mph).

The test procedure was repeated following the accumulation of nearly 3,000 km of operational testing. The vehicle had been modified with various acoustic treatments both to the engine cover and air-inlet area. Sound level measurements were compared for unladen vehicle conditions before and after modifications.

3.5.2 Wayside Noise

Located at the designated distance from the track, test personnel measured and recorded the peak dB(A) reading observed for the passing railbus. The vehicle was to travel past the sampling point at cruise speeds including 31, 48, 64 and 72 kph. The vehicle was turned 180° at the end of each pass and readings again taken for the same speeds in the opposite direction.

3.6 METHOD OF ANALYSIS

The average and peak dB(A) readings observed from the hand held sound level meter were recorded and later tabulated to form a comparison of the effect of operating the vehicle at various speeds.

Measurements recorded were also used to compare the improvements to ride comfort following the vehicle modifications and to assess the recorded levels of ride quality.

3.7 RESULTS

The test results were recorded on test data sheets for both onboard and wayside vehicle noise levels. A retest for onboard noise levels was made following modifications to reduce the engine and drive noise measured during operational speeds up to and including 72 kph.

Vehicle modifications prior to the retest included:

- engine acoustic cover (50 mm thick);
- addition of inlet air-silencer;
- replacement of inlet filter (dry-type);
- acoustic lining in inlet air-box;
- isolation of exhaust vibrations with rubber mounts;
- reduction of drive-shaft vibrations (See Ref. 4).

The first set of tests for onboard and wayside noise was performed prior to the mileage accumulation exercise while the retest (onboard noise) was made following the accumulation of nearly 3,000 km. Locations of the five test zones for onboard vehicle noise measurements is shown in Figure 1.0.

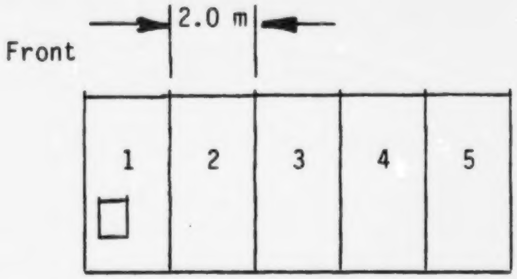

FIGURE 1.0: VEHICLE TEST ZONES

Date	Vehicle Speed (kph)	dB(A) In Test Zone				
		1	2	3	4	5
26 Sept. 1985	32	90	87	81	78	76
	48	91	87	83	81	78
27 Sept. 1985	64	92	89	84	83	81
	72	93	89	86	84	82

TABLE 1.0: ONBOARD VEHICLE NOISE -dB(A)
(Prior to Modifications)

Date	Vehicle Speed (kph)	dB(A) In Test Zone				
		1	2	3	4	5
01 Nov. 1985	32	82	81	79	79	78
	48	85	84	82	83	82
	64	86	86	84	85	85
	72	88	87	86	86	86

TABLE 2.0: ONBOARD VEHICLE NOISE -dB(A)
(After Modifications and Mileage Accumulation)

Date	Vehicle Speed (kph)	Wayside Noise Level dB(A)
26 Sept. 1985	32	78
	48	82
	64	84
	72	85

TABLE 3.0: WAYSIDE NOISE LEVELS - dB(A)

Test results for averaged onboard noise levels measured within each zone of the railbus prior to and after modifications is summarized in Tables 1.0 and 2.0.

Test results for peak wayside noise levels measured for the railbus is summarized in Table 3.0.

3.8 CONCLUSIONS

The onboard and wayside noise levels were measured while operating the WCSS Railbus at various track speeds. All tests were conducted on a designated test section of the INCO Railway Line.

Following minor modifications to the railbus' engine and drive train system, onboard noise levels (within the driver's section) of 85-87 dB(A) were measured at a maximum recommended vehicle cruise speed of 72 kph. The recommended acceptable standard values specified by CN for continuous noise in a locomotive cab is shown in Table 4.0:

Duration Permitted (Hours)	Sound Level -dB(A)
12	87
8	90
6	92
4	95
2	100

TABLE 4.0: RECOMMENDED NOISE LEVELS FOR VEHICLE OPERATIONS

From the test results, it can be summarized that the time-weighed averaged onboard noise levels measured for the WCSS Railbus is acceptable at the driver's position. In addition, the noise measurement within the railbus passenger area is viewed as being acceptable for passenger comfort for trips of a few hours duration likely in the Thompson area.

4.0 VIBRATION

4.1 TEST OBJECTIVE

To gather quantitative data on the vertical and lateral accelerations of the vehicle axles during normal operation to allow engineering assessment of wheel bearing performance requirements.

4.2 TEST APPROACH

Direct measurement of wheel accelerations was avoided because of complexity, expense and time constraints. Vertical and lateral accelerations were measured, instead, on the bearing housings close to the wheel on both the front and rear axles. Because of the high bearing stiffness, these measurements were used for the engineering evaluation of bearing performance and life.

Measurements were made over the vehicle's operating range of speed and load.

4.3 INSTRUMENTATION AND EQUIPMENT

- 1 accelerometer, 0 to ±5 g;
- 1 accelerometer, 0 to ±30 g;
- 1 accelerometer, 0 to ±10 g;
- 1 ±12 VDC regulated power supply, to provide excitation voltage for accelerometers;
- 1 2-channel Strip Chart Recorder, with 100 K ohm input impedence and a half-scale frequency response flat with 1 dB to 30 Hz;
- 110 VAC power source for the chart recorder (used the TTL APU carried on-board the vehicle);

- 2 10 m lengths of 4 conductor cable;
- 1 DC voltage power supply, variable from 0 to ±5 V; and
- 1 digital voltmeter.

Each accelerometer was calibrated by the UTDC Instrumentation Department.

4.4 TEST SET-UP

Two accelerometers were mounted on an 8" length of angle iron:

- the 0 to ±5 g accelerometer to measure accelerations in the lateral direction;

- the 0 to ±30 g accelerometer to measure accelerations in the vertical direction. In later tests, this accelerometer was replaced by a more sensitive 0 to ±10 g accelerometer.

The angle iron bracket was rigidly fastened to the front axle housing over each end of a U bolt and plate holding the left front leaf spring to the axle housing.

Cable from each accelerometer was routed to the main instrumentation station located at the rear of the bus interior. A regulated DC power supply was connected to provide the required ±12 V excitation for each accelerometer. Output signals from each accelerometer were sent to the 2-Channel Strip Chart Recorder.

The angle iron bracket carrying each accelerometer was later moved to the rear axle housing and attached in an identical manner over the U bolt and plate holding the left rear spring to the rear axle housing.

4.5 TEST PROCEDURES

Before attaching the angle bracket retaining the two accelerometers to the axle housing, each accelerometer was oriented in 90° steps to experience conditions of +1 g, 0 g and -1 g respectively. In each orientation, the voltage output from the accelerometer was measured using a digital voltmeter in place of the strip chart recorder. Output values were recorded and verified with the calibration values provided by the MCL Instrumentation Department.

The accelerometers were mounted initially on the front axle housing. The bus, in the unladen condition, was taken to the test portion of the INCO track (mile 16), consisting of 2 km of tangent track in Class 4 condition.

Using a variable DC power supply and digital voltmeter, amplitude on the strip chart recorder was calibrated for each of the two channels to give:

- for the vertical accelerometer channel, 5 mm deflection for 1 g acceleration (full scale = ±5 g); and

- for the lateral accelerometer channel, 10 mm deflection for 1 g acceleration (full scale = ±2.5 g).

The bus was accelerated from rest to a true speed of 48 km/h (30 mph), travelling south on the test portion of track. Strip chart recordings, at paper speeds of 10 mm/s, 25 mm/s and then 100 mm/s were taken of the vertical and lateral accelerations in real time for a duration of about 20 seconds.

This procedure was repeated for a true speed of 72 km/h (45 mph). The bus was then turned, and the above procedure repeated with the bus now travelling north on the test portion of track.

The accelerometers were then mounted on the rear axle housing. The above procedures were again repeated, including calibrations, to obtain recordings of rear axle housing accelerations for two operating speeds and two directions.

The bus was loaded with ballast to its gross vehicle weight of 12,020 kg (26,500 lb). The vertical accelerometer was replaced by a more sensitive one (0 to ±10 g) after measurements in the unladen condition had shown lower accelerations than were previously anticipated. Calibrations were redone and the above procedures repeated, with the accelerometers mounted on the rear axle housing only.

During the course of the tests, vertical and lateral accelerations of the axle housings were occasionally recorded at other locations and speeds on the INCO track, while curving and while travelling through switches.

4.6 METHOD OF ANALYSIS

The strip chart recordings of each test run were analyzed in the following manner.

The relevant calibrations of lateral and vertical acceleration versus strip chart amplitude, carried out prior to each set of runs, were first examined and confirmed. Each calibration was taken as linear. A 10 second to 20 second time interval was selected from the test time of each chart recording. Peak values of acceleration were identified and an average level determined from the amplitudes observed.

As mentioned previously, paper speed for the chart recordings was changed during each run, generally from 25 mm/s to 100 mm/s. The time histories were examined for obvious or predominant frequencies.

4.7 RESULTS

Representative strip chart recordings for vertical and lateral accelerations measured on the rear axle housing are shown in Figure 2.

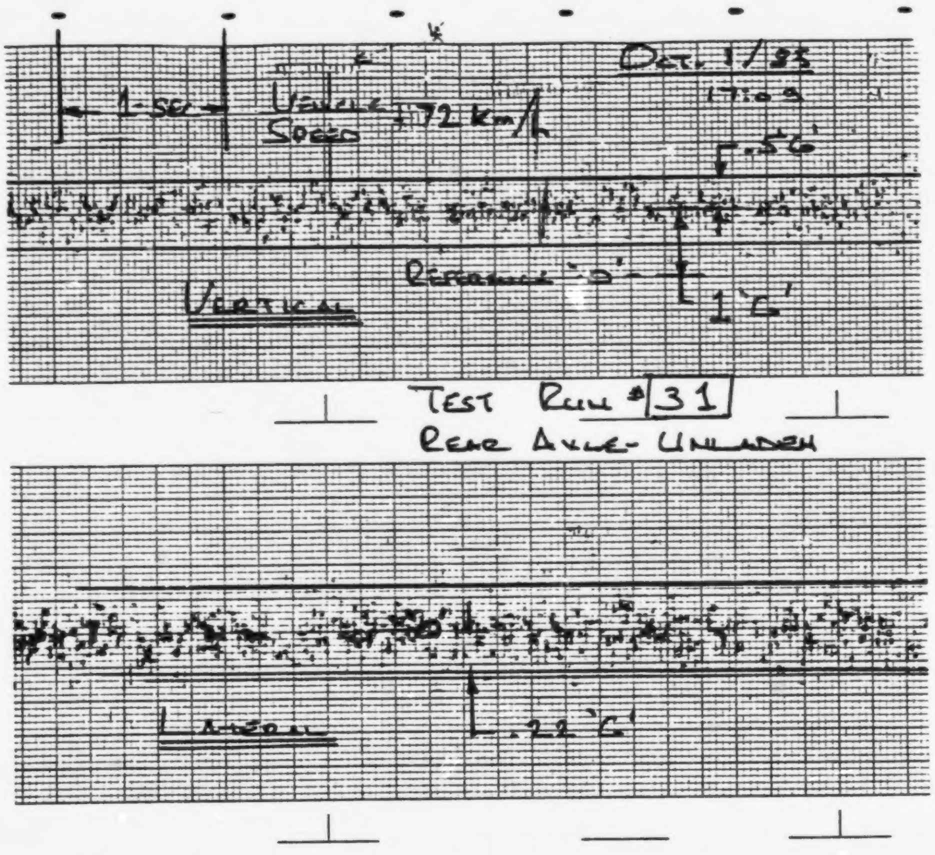

FIGURE 2: CHART RECORDINGS, VERTICAL AND LATERAL ACCELERATIONS

The average and peak accelerations measured on the front and rear axle housings are compiled in Tables 5, 6, 7, and 8. Measurements are included over the vehicle's full operating range. Vertical accelerations are given relative to a steady 1 g downward value.

UNLADEN VEHICLE, FRONT AXLE HOUSING ACCELERATION DATA
TEST DATE: 1 OCTOBER 1985

Run No.	- Time	Vertical "g"		Lateral "g"		Conditions/Location
		Average	Peak	Average	Peak	
2	10:00	±0.5	1.5	±0.3	0.8	48 kph (30 mph), south on test section
2	13:01	±0.4	1.4	±0.2	0.6	48 kph (30 mph), north on test section
3	10:15	±0.6	1.8	±0.3	0.6	72 kph (45 mph), south on test section
13	13:10	±0.5	1.6	±0.2	0.6	80 kph (50 mph), north on test section
14	13:15	±0.5	2.1	±0.2	0.4	89 kph (55 mph), north on test section
6	11:00	±0.5	1.8	±0.3	0.6	60 kph (37 mph), south, right hand curve
6a	11:00	±0.5	1.6	±0.3	0.8	60 kph (37 mph), south, left hand curve
15a	13:30	±0.5	1.5	±0.3	0.6	48 kph (30 mph), north, left hand curve
8	11:45	±0.2	2.3	±0.3	0.7	through switch, INCO yard, 8 kph (5 mph)
15	13:20	±0.3	1.5	±0.1	0.6	highway crossing, north, 8 kph (5 mph)
7	11:38	±0.5	1.2	±0.3	0.9	low speed, "wye" at Pipe Lake, poor section

TABLE 5: FRONT AXLE ACCELERATIONS, UNLADEN VEHICLE

UNLADEN VEHICLE, REAR AXLE HOUSING ACCELERATION DATA
TEST DATE: 1 OCTOBER 1985

Run No.	Time	Vertical "g"		Lateral "g"		Conditions/Location
		Average	Peak	Average	Peak	
17	15:36	±0.5	1.3	±0.2	0.5	48 kph (30 mph), south on test section
28	16:45	±0.5	2.3	±0.2	0.7	64 kph (40 mph), south on test section
30	17:05	±0.5	1.7	±0.2	0.5	64 kph (40 mph), north on test section
31	17:09	±0.5	2.1	±0.3	0.6	72 kph (45 mph), north on test section
19	15:38	±0.4	1.4	±0.2	0.6	48 kph (30 mph), right hand curve, south
22	15:45	±0.5	1.9	±0.2	0.6	48 kph (30 mph), left hand curve, south
23	15:50	±0.4	0.9	±0.2	0.5	48 kph (30 mph), right hand curve, south
33	17:14	±0.4	2.1	±0.3	0.9	56 kph (35 mph), left hand curve, north
21	15:40	±0.3	2.8	±0.2	1.0	level crossing, Pipe Lake, south
32	17:10	±0.3	2.4	±0.2	0.7	highway crossing, north

TABLE 6: REAR AXLE ACCELERATIONS, UNLADEN VEHICLE

UNLADEN VEHICLE, REAR AXLE HOUSING ACCELERATION DATA
TEST DATE: 8 NOVEMBER 1985

Run No.	Time	Vertical "g"		Lateral "g"		Conditions/Location
		Average	Peak	Average	Peak	
4	13:15	±0.5	2.4	±0.3	1.2	48 kph (30 mph), north on test section
6	13:31	±0.5	2.3	±0.3	1.2	48 kph (30 mph), south on test section
5	13:30	±0.7	1.7	±0.4	0.9	72 kph (45 mph), north on test section
7	13:36	±0.6	1.8	±0.3	1.1	72 kph (45 mph), south on test section
3	13:00	±0.1	2.2	±0.1	0.9	low speed, poor track

TABLE 7: REAR AXLE ACCELERATIONS, UNLADEN VEHICLE, AFTER DESIGN MODIFICATIONS

UNLADEN VEHICLE, REAR AXLE HOUSING ACCELERATION DATA
TEST DATE: 11 NOVEMBER 1985

Run No.	Time	Vertical "g"		Lateral "g"		Conditions/Location
		Average	Peak	Average	Peak	
4	10:15	±0.9	2.0	±0.5	1.1	48 kph (30 mph), south on test section
7	14:09	±0.8	2.0	±0.4	0.7	48 kph (30 mph), north on test section
5	10:25	±0.9	3.4	±0.5	1.4	72 kph (45 mph), south on test section
18	14:13	±1.0	2.2	±0.5	1.0	72 kph (45 mph), north on test section
10	14:55	±0.6	3.0	±0.3	1.1	45 kph (28 mph), north, left hand curve
11	15:00	±0.8	4.2	±0.4	1.1	51 kph (32 mph), north, right hand curve
13	16:03	±0.8	3.6	±0.3	1.5	24 kph (15 mph), north, right hand curve
14	16:04	±0.5	3.4	±0.2	1.1	24 kph (15 mph), south, right hand curve
15	16:06	±0.4	4.0	±0.2	0.9	16 kph (10 mph), over switch, INCO Yard

TABLE 8: REAR AXLE ACCELERATIONS, FULLY LADEN VEHICLE

For the unladen vehicle, the average vertical accelerations experienced by the front and rear axle housings under normal operating conditions is about 0.5 g, with occasional peaks reaching 2.8 g. Lateral accelerations average about 0.3 g, with peaks reaching 1.2 g.

For the fully laden vehicle, the average vertical accelerations increased to 0.9 g, with peaks to 4.2 g. The average lateral accelerations were 0.5 g, with peaks reaching 1.5 g.

4.8 CONCLUSIONS

Vertical and lateral accelerations have been measured for the front and rear axle housings of the WCSS railbus during normal operation. For bearing life calculations, average values for the fully laden vehicle were found to be 0.9 g vertical, and 0.5 g lateral.

5.0 RIDE QUALITY

5.1 TEST OBJECTIVE

Quantify the ride comfort on the bus to a recognized standard.

5.2 TEST APPROACH

The British Rail Ride Index was selected as the recognized industry standard to which the bus ride quality will be compared. Tangent track, reasonably representative of the "commercial standard", was used for the tests. Ride was examined with the bus in both the unladen and fully laden condition.

5.3 INSTRUMENTATION AND EQUIPMENT

- 1 British Rail Ridemeter, Model MKII, with visual analog indicator and battery power source.
- 1 2-Channel Strip Chart Recorder
- 1 10 m length, 2 wire cable with phono jack (end 1) to banana plug (end 2), connecting Ridemeter to Strip Chart Recorder.
- 110 VAC Power Source for Chart Recorder (from on-board APU).

The Ridemeter was calibrated by the MCL Instrumentation Department using a certified standard.

5.4 TEST SET-UP

The portable Ridemeter was connected with a 10 m length of cable to the Strip Chart Recorder located at the main instrumentation station on the bus. Location markers were placed at three positions along the bus aisle-way:

Position 1: 1 m rear of the front axle centreline
Position 2: 3 m rear of the front axle centreline (about midway between the axle centres)
Position 3: Over the rear axle centreline.

The aisle-way was kept clear.

5.5 TEST PROCEDURES

1. The bus, in the unladen condition, was taken to the test portion of the INCO track (mile 16), consisting of 2 km of tangent, level track in Class 4 condition.

2. The Ridemeter was set to the 0-6 BR No. scale, and to position 'B' for time averaging of about 10 seconds.

3. Using the calibration button and potentiometer on the Ridemeter, analog readings from the Ridemeter indicator were calibrated against amplitude on the Strip Chart Recorder. A Ridemeter indication of (BR No.) six (6) was made to correspond to a full scale amplitude of 25 mm on the Strip Chart.

4. The Ridemeter was placed on the aisle-way floor at Position 1, switched to "Vertical" ride and power "ON".

5. The bus was accelerated from rest to the maximum operating true speed of 72 km/h (45 mph).

6. Strip chart recordings, at a paper speed of 10 mm/s, were taken of the BR meter output for a duration of 10 to 20 seconds.

7. Simultaneously with the chart recording, visual readings of the average and peak values for Ride Number were read from the Ridemeter indicator and recorded.

8. The Ridemeter, still at Position 1, was switched to "Horizontal" ride. Steps 5 to 7 were repeated.

9. The Ridemeter was placed at Position 2, and Steps 5 to 8 repeated.

10. The Ridemeter was placed at Position 3, and Steps 5 to 8 repeated.

11. Travelling north on the test portion of track, Steps 5 to 10 were repeated at the maximum operating speed of 72 km/h (45 mph).

12. At the completion of runs, a second Strip Chart calibration was made (Step 3).

13. The bus was loaded with ballast to its gross vehicle weight of 12,020 kg (26,500 lbs). Steps 1 to 12 were repeated.

5.6 METHOD OF ANALYSIS

The strip chart recordings of each test run were analyzed in the following manner.

a) A calibration curve was first plotted of BR Number versus strip chart amplitude using the chart calibration data gathered before and after the test runs (Step 3 of 5.5).

A computer-generated second order polynomial "least squares" fit was made to the data, yielding a functional relationship between strip chart amplitude and BR Number.

b) A 10 second to 15 second time interval was selected from the test time of each chart recording; minimum, peak and average values of signal amplitude were measured from the selected time interval.

c) Using the calibration function, measured strip chart amplitudes were converted to BR Numbers and tabulated.

d) The visual readings recorded from the Ridemeter indicator during each test run (Step 7 of 5.5) were also tabulated and used for substantiation of each test run.

e) The above analysis was carried out for both the "unladen" vehicle and for the fully laden vehicle.

5.7 RESULTS

Representative strip chart recordings for vertical and lateral ride index number are shown in Figures 3 and 4:

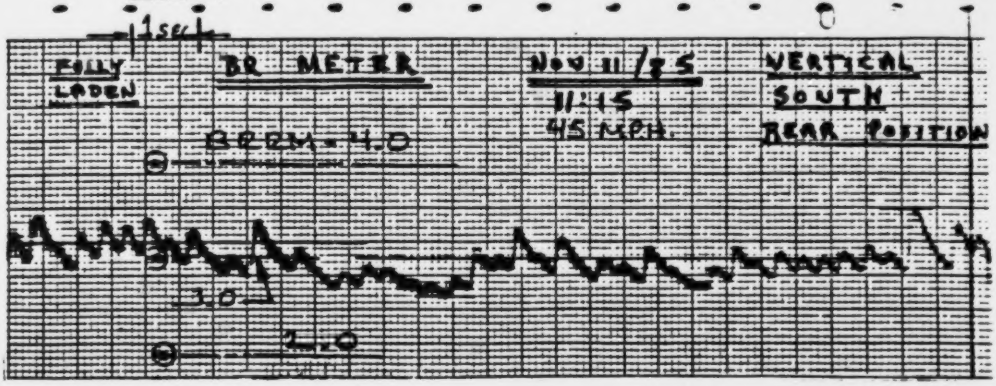

FIGURE 3: SAMPLE RIDEMETER OUTPUT (VERTICAL)

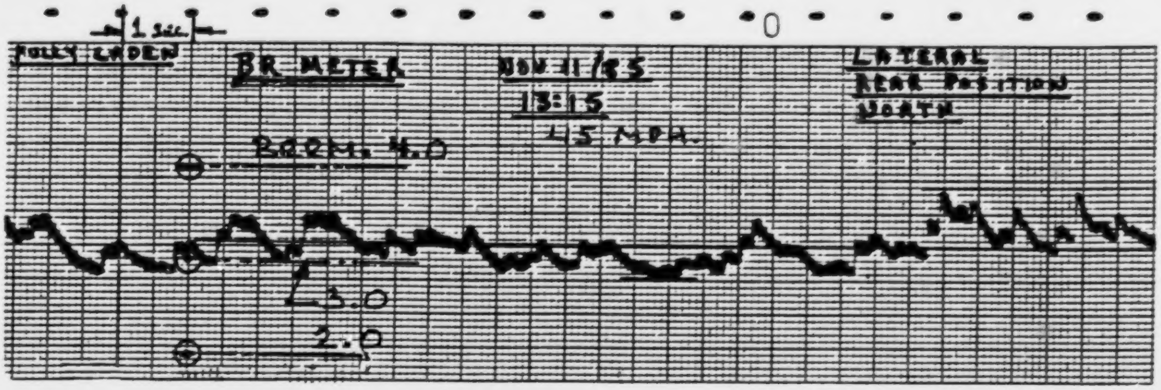

FIGURE 4: SAMPLE RIDEMETER OUTPUT (LATERAL)

A compilation of meter readings and chart recorded values for British Ride Number are given in Tables 9,10 and 11.

RIDE QUALITY MEASUREMENTS - British Rail Meter

UNLADEN VEHICLE
SPEED = 45 mph

Recorded Readings Min	Recorded Readings Peak	Recorded Readings Avg	Meter Readings Avg	Meter Readings Peak					
		VERTICAL RIDE							
2.92	5.53	3.53	3.3	3.4	Sep 28	15:55	Front	Vertical	South
3.03	4.11	3.74	3.3	3.6	Sep 28	15:55	Front	Vertical	North
2.97	4.82	3.63	3.3	3.5	Mean Values				
3.06	4.22	3.69	3.3	3.6	Sep 28	15:55	Mid	Vertical	South
3.14	4.13	3.53	3.3	3.6	Sep 28	15:55	Mid	Vertical	North
3.10	4.18	3.61	3.3	3.6	Mean Values				
2.99	4.55	3.69	3.3	3.6	Sep 28	15:55	Rear	Vertical	South
3.14	4.41	3.69	3.3	3.6	Sep 28	15:55	Rear	Vertical	North
3.06	4.48	3.69	3.3	3.6	Mean Values				
		LATERAL RIDE							
3.14	4.75	3.78	3.6	3.8	Sep 28	15:55	Front	Lateral	South
3.21	5.32	3.95	3.5	3.8	Sep 28	15:55	Front	Lateral	North
3.18	5.03	3.87	3.6	3.8	Mean Values				
2.78	3.53	3.14	2.8	3.0	Sep 28	15:55	Mid	Lateral	South
2.88	3.91	3.29	3.0	3.4	Sep 28	15:55	Mid	Lateral	North
2.83	3.72	3.21	2.9	3.2	Mean Values				
2.85	4.90	3.29	3.0	3.3	Sep 28	15:55	Rear	Lateral	South
2.78	4.13	3.29	3.2	3.4	Sep 28	15:55	Rear	Lateral	North
2.81	4.52	3.29	3.1	3.4	Mean Values				

TABLE 9: RIDE QUALITY MEASUREMENTS - British Rail Meter

UNLADEN VEHICLE (after modifications for vibration)
SPEED = 45 mph

Recorded Readings Min	Recorded Readings Peak	Recorded Readings Avg	Meter Readings Avg	Meter Readings Peak					
			VERTICAL RIDE						
			3.3	3.6	Oct 31	14:00	Front	Vertical	South
			3.3	3.6	Oct 31	14:00	Front	Vertical	North
			3.3	3.6	Mean Values				
			3.4	3.6	Oct 31	14:00	Mid	Vertical	South
			3.2	3.4	Oct 31	14:00	Mid	Vertical	North
			3.3	3.5	Mean Values				
			3.2	3.6	Oct 31	14:00	Rear	Vertical	South
			3.3	3.6	Oct 31	14:00	Rear	Vertical	North
			3.3	3.6	Mean Values				
			LATERAL RIDE						
			3.6	4.0	Oct 31	14:00	Front	Lateral	South
			3.4	4.0	Oct 31	14:00	Front	Lateral	North
			3.5	4.0	Mean Values				
			3.0	3.2	Oct 31	14:00	Mid	Lateral	South
			2.9	3.0	Oct 31	14:00	Mid	Lateral	North
			3.0	3.1	Mean Values				
			3.2	3.4	Oct 31	14:00	Rear	Lateral	South
			3.2	3.4	Oct 31	15:55	Rear	Lateral	North
			3.2	3.4	Mean Values				

TABLE 10: RIDE QUALITY MEASUREMENTS - British Rail Meter

FULLY LADEN VEHICLE
SPEED = 45 mph

Recorded Readings Min	Recorded Readings Peak	Recorded Readings Avg	Meter Readings Avg	Meter Readings Peak					
		VERTICAL RIDE							
2.83	3.96	3.36	3.2	3.4	Nov 11	10:42	Front	Vertical	South
2.83	3.83	3.44	3.3	3.4	Nov 11	13:40	Front	Vertical	North
2.83	3.90	3.40	3.3	3.4	Mean Values				
2.83	3.87	3.36	3.0	3.5	Nov 11	10:59	Mid	Vertical	South
2.90	3.96	3.44	3.4	3.5	Nov 11	13:24	Mid	Vertical	North
2.86	3.92	3.40	3.2	3.5	Mean Values				
2.49	3.44	2.97	3.1	3.3	Nov 11	11:15	Rear	Vertical	South
2.76	4.85	3.44	3.2	3.8	Nov 11	13:09	Rear	Vertical	North
2.63	4.15	3.21	3.2	3.6	Mean Values				
		LATERAL RIDE							
2.83	5.40	3.87	3.8	4.2	Nov 11	10:50	Front	Lateral	South
2.83	4.59	3.69	3.6	4.0	Nov 11	13:50	Front	Lateral	North
2.83	4.99	3.78	3.7	4.1	Mean Values				
2.53	3.52	3.05	3.0	3.3	Nov 11	11:06	Mid	Lateral	South
2.56	3.69	3.05	3.1	3.4	Nov 11	13:32	Mid	Lateral	North
2.54	3.61	3.05	3.1	3.4	Mean Values				
2.53	3.44	2.90	3.0	3.4	Nov 11	11:22	Rear	Lateral	South
2.69	3.78	3.05	3.1	3.2	Nov 11	13:15	Rear	Lateral	North
2.61	3.61	2.97	3.1	3.3	Mean Values				

TABLE 11: RIDE QUALITY MEASUREMENTS - British Rail Meter

From the tables, it is evident that average readings taken visually from the analogue meter were consistently lower than those recorded on strip chart by an amount of about 0.3. British Ride Number values determined from the chart recordings are considered to be the correct measured values.

The British Rail Ride Index units which define ride quality in terms of passenger comfort are given below:

RIDE INDEX	QUALITY OF RIDE
1.0	Very good
1.5	Almost very good
2.0	Good
2.5	Almost good
3.0	Satisfactory
3.25	Satisfactory with limitations
3.5	Just satisfactory
4.0	Operable
4.5	Not operable
5.0	Dangerous

5.8 DISCUSSION AND CONCLUSIONS

Ride Quality - Vertical

At all measurement locations on the bus, ride quality in the vertical direction was found to be similar. With the bus in the unladen condition, an average British Ride Number of 3.6 was measured which corresponds to a "just satisfactory" quality of ride. Very little change in vertical ride for the unladen vehicle was noted after some design modifications were made to reduce vibration.

As expected, with the bus in the fully laden condition, the vertical ride quality improved somewhat to an average BR Number of 3.3, which is "satisfactory with limitations".

Ride Quality - Lateral

Lateral ride measured at the front of the bus was consistently worse than that measured at the mid and rear positions. Engine-related vibration and interference may be responsible for this effect, since vehicle motion such as "yaw" should result in poorer ride at both the front and rear locations.

For the unladen bus, an average British Ride Number of 3.9 corresponding to just an "operable" lateral ride was measured at the front of the bus, while at the mid and rear positions, this value fell to 3.25, a "satisfactory with limitations" condition. A slight improvement in lateral ride was noted after modifications for vibration were made.

Again, with the bus in the fully laden condition, the lateral ride quality was somewhat better, with an average BR Number at the front of 3.8, falling to a value of 3.0, "satisfactory", at the mid and rear positions.

In general, the ride quality for the WCSS railbus is considered as "just satisfactory", and improvements to the overall suspension design should be considered for a new vehicle.

6.0 WHEEL/RAIL INTERFACE

6.1 STABILITY

6.1.1 Test Objective

To validate that the vehicle remains laterally stable up to and including the desired operational speed of 72 km/h (45 mph).

6.1.2 Test Approach

The stability was examined by video observation of each wheel/rail interface and assessment of vehicle behavior at various speeds.

6.1.3 Instrumentation and Equipment

- 4 video cameras (1 per wheel), each with power supply;
- 4 floodlights, 12-VDC (illumination of each wheel);
- 2 two-way video mixers for split screen representation;
- 2 video monitors;
- 1 date/time impression generator;
- 1 video tape (VHS) cassette recorder, equipped with audio dubbing (microphone) and an accurate tape position indicator, both used to correlate video records with event markers;
- 1 onboard APU providing 110 V AC power for video equipment;
- 1 12 VDC power source of floodlights, taken from vehicle electrical system;
- 2 10 m lengths, BNC cable;
- 1 6 m length, BNC cable;
  several assorted lengths, BNC cable (2 m - 3 m);
- 2 video tapes (VHS).

6.1.4 Test Set-Up

Each of the four (4) video cameras, housed in a plastic case for environmental protection, was mounted to the underside of the vehicle, and focussed on the wheel/rail interface of each of the four (4) wheels respectively. Due to mounting considerations, each camera was located to the rear of its respective wheel, facing in the forward direction. A floodlamp was mounted adjacent to each camera to increase the illumination of the fields of view.

Cabling for video signal, synchronization and power was routed from each camera and floodlamp to the main instrumentation station located at the rear of the bus interior. Video signals from the two (2) front wheel cameras were fed to a 2-channel mixer. Output from the mixer was fed through a date/time impression generator and onward to a monitor where both wheels could be observed on a split screen image in real time.

Video signals from the two (2) rear wheel cameras were connected in a similar fashion to a second mixer and monitor to produce a second split screen image.

A video tape recorder (VHS) was connected, as required, to either of the monitors in order to record the visual observations. A microphone to the VCR was used for audio documentation, and a tape position indicator used to correlate the recording with hand written notes.

6.1.5 Test Procedure

The bus, in the unladen condition, was taken to the test portion of INCO track (mile 16), consisting of 2 km of tangent track in Class 4 condition. En route, the complete video system was powered up and the video monitors observed. Random video recordings were made of the wheel/rail interface, noting the vehicle stability. Protective transparent covers in front of each video camera were cleaned of dirt and debris as required throughout the tests.

At the test section of track, the video recorder was connected to record the front wheel behavior. The vehicle was accelerated from rest to a speed of 48 km/h (30 mph), travelling south. The audio dubbing facility on the video recorder was used to note the speed. Acceleration was then continued to speeds of 56 km/h (35 mph), 64 km/h (40 mph), and 72 km/h (45 mph) and 80 km/h (50 mph), noting the speed on the voice track in each case. The vehicle was then decelerated, again noting speed.

The observations were repeated, travelling north along the test portion of track. The video recorder was then connected to observe the rear wheels, and the procedures repeated. The bus was then returned to the INCO yard, again making occasional recordings of stability.

The bus was loaded with ballast to its gross vehicle weight of 12,020 kg (26,500 lbs). The above tests were repeated in the same manner, observing only the front wheels for the fully laden vehicle.

6.1.6 Method of Analysis

The video record was closely examined. In particular, a search was made for any indication of extreme flanging, rail climbing or lateral cyclic motion of undamped or increasing amplitude.

6.1.7 Results

The test runs are recorded on video cassette.

Unladen vehicle:	VHS cassette, WCSS Bus Tests, Sept 28 - Oct 1 1985
Fully laden vehicle:	VHS cassette, WCSS Bus Tests, Nov 11 1985

No indication of extreme flanging, rail climbing or lateral cyclic motion of undamped or increasing amplitude was found in any of the tests. Speeds up to 90 km/h (56 mph) were reached on the test portion of track with the unladen vehicle.

6.1.8 Conclusions

The WCSS Flyer bus modified for use on standard gage railway track exhibited no indications of instability, either empty or at rated load, at any speed up to and including 90 km/h.

6.2 CURVING PERFORMANCE

6.2.1 Test Objectives

To identify any tendency for the vehicle to derail while negotiating curves of various radii encountered in its normal operation.

6.2.2 Test Approach

Curving behavior was determined by video observation of each wheel/rail interface as the vehicle negotiated curves of various radii at the expected operational speeds. A careful examination was made for any tendency of the wheel flanges to climb the rail, and the general behavior of the vehicle noted.

6.2.3 Instrumentation and Equipment

The video instrumentation and equipment used to examine stability was also used to determine curving behavior, and is outlined in Section 6.1.3.

6.2.4 Test Set-Up

The test set-up of instrumentation was identical to that used for stability tests and is outlined in Section 6.1.4.

6.2.5 Test Procedure

The bus, in the unladen condition, was taken to the main switch yard outside INCO's production and maintenance facilities in Thompson. At this location, a "wye" section of track contains curves in both left and right directions of 175 m (573 ft) radius. The transparent protective covers in front of each video camera were cleaned, and the video recorder connected to record the front wheel behaviour.

The vehicle was driven at a steady speed of 16 kph (10 mph) into the left hand curve. Each video monitor was observed and the vehicle behaviour noted. The bus was then reversed at a steady speed of 16 kph back through the same curve, with similar observations made.

This procedure was repeated with forward speeds of 24 kph (15 mph) and 48 kph (30 mph) in the forward direction and at 24 kph in the reverse direction.

The same procedure was followed for the right hand curve.

Observations were also made at various left and right curves of about 350 m radius along the INCO line, travelling at forward speeds averaging 48 kph. The vehicle, in the fully laden condition, was observed for general curving behaviour during other tests.

6.2.6 Method of Analysis

The video records were closely examined. In particular, a search was made for any indication of extreme flanging or rail climbing.

6.2.7 Results

The test runs are recorded on video cassette.

Unladen vehicle:	VHS cassette, WCSS Bus Tests, Sept 28 - Oct 1 1985
Fully laden vehicle:	VHS cassette, WCSS Bus Tests, Nov 11 1985.

No evidence of extreme flanging or rail climbing were observed showing no tendency to derail at the speeds tested.

6.2.8 Conclusions

The WCSS Flyer bus modified for use on standard gage railway track has satisfactory curving ability for track typical of northern conditions of the curvatures noted.

6.3 SWITCHING BEHAVIOR

6.3.1 Test Objective

To identify any tendency for the vehicle to derail, damage switch equipment or follow the wrong alignment as it travels through a switch.

6.3.2 Test Approach

Switching behavior was determined by video observation of each wheel/rail interface as the vehicle travelled through several different switches on the INCO line at the expected operational speeds. A careful examination was made for any tendency of the wheels to derail or follow the wrong alignment. In addition, a visual inspection was made of each switch before and after the test and each wheel for any apparent damage.

6.3.3 Instrumentation and Equipment

The video instrumentation used to determine switching behavior was that used to examine stability and is described in Section 6.1.3.

6.3.4 Test Set-Up

The instrumentation was set up as for the stability tests and is described in Section 6.1.4. Switches at the INCO yard were used for the tests.

6.3.5 Test Procedure

The railbus, in the unladen condition, was taken to the main switch yard outside INCO's production and maintenance facilities in Thompson. The transparent protective covers in front of each video camera were cleaned, and the video recorder connected to record the front wheel behaviour.

The bus was driven at a steady speed of 8 kph (5 mph) through a selected track switch. Each video monitor was observed and the vehicle behaviour noted. The bus was then reversed at the same speed back through the switch, with similar observations made.

This procedure was repeated with forward and reverse speeds of 16 kph (10 mph) and 24 kph (15 mph).

Observations were also made as the vehicle passed through other switches, and with the vehicle in the fully laden condition.

6.3.6 Method of Analysis

The video record was closely examined. In particular, a search was made for any indication of extreme flanging, rail climbing and any tendency to split the switch.

6.3.7 Results

The test runs are recorded on video cassette.

Unladen vehicle:	VHS cassette, WCSS Bus Tests, Sept 28 - Oct 1 1985.
Fully laden vehicle:	VHS cassette, WCSS Bus Tests, Nov 11 1985.

No indication of extreme flanging, climbing or switch splitting was found when the vehicle travelled though any switch in either forward or reverse direction up to speeds of 24 kph.

6.3.8 Conclusions

The WCSS Flyer bus modified for use on standard gage railway track has satisfactory switching ability.

7.0 FUEL CONSUMPTION

7.1 TEST OBJECTIVE

To determine the fuel consumption of the WCSS Railbus during a representative general service operation.

7.2 TEST APPROACH

During the mileage accumulation exercise, tests were conducted to evaluate the fuel consumed (diesel) while operating on the INCO Railway Line for both unladen and loaded vehicle configurations.

7.3 INSTRUMENTATION AND EQUIPMENT

- Graduated container, 10 litre capacity;
- Graduated container, 1 litre capacity;
- Funnel; and
- Hubodometer.

7.4 TEST SET-UP

Not applicable

7.5 TEST PROCEDURE

The vehicle fuel tank was filled to the brim; the hubodometer indication was noted in the log book. The vehicle was then operated over a recorded distance in a variety of ways, details of which were recorded in the Operation Log Book. The quantity of fuel required to refill the tank to the brim was then measured, and the fuel consumption rate calculated.

7.6 METHOD OF ANALYSIS

Arithmetic:

Distance ÷ Fuel consumed = consumption rate.

7.7 RESULTS

The test runs are recorded in the operational logbook, and are summarized in the following table:

DATE	KM	FUEL USED (litres)	CONSUMPTION (km/L)
01 Nov '85	101.68	17.8	5.71
09 Nov '85	74.39	16.0	4.65
11 Nov '85			
(trip 1)	113.14	38.2	2.96
(trip 2)	73.03	14.2	5.15

TABLE 12: FUEL CONSUMPTION RESULTS

NOTES:

- 01 Nov. run was unladen, little reversing;
- 09 Nov. run was unladen, some idling, little reversing;
- 11 Nov. trip 1 was fully laden, much reversing and much idling for test runs;
- 11 Nov. trip 2 was fully laden, minimal idling, little reversing;

7.8 CONCLUSIONS

Based on the two representative runs, 01 Nov., and the second run of 11 Nov., the WCSS Railbus modified for use on standard gauge railway track in typical operation is likely to consume fuel (diesel) at an average rate of 5.43 km/L (15 mpg).

8.0 RELIABILITY AND WEAR (WHEELS)

8.1 TEST OBJECTIVE

To evaluate the reliability and wear of the WCSS Railbus wheels modified for rail use.

8.2 TEST APPROACH

The two front wheels were measured for lateral run-out on 06 September 1985. Results indicated unacceptable lateral measurements (wobble). All four wheels were removed and remachined to an acceptable tolerance. It is felt that this lateral movement would affect the stability and ride comfort of the Railbus.

8.3 INSTRUMENTATION AND EQUIPMENT

- o 1 - dial indicator;
- o 1 - wheel tread measuring device; and
- o 1 - hubodometer.

8.4 TEST SET-UP

Lateral run-out

The test was set up using the axle centerline as the reference point. The dial indicator was anchored to the running rail and measured lateral run-out on the machined surface of the wheel.

8.4.1 Wheel Eccentricity (Vertical)

The test is similar to the lateral run-out, the difference being the measuring point.

8.4.2 Wheel Tread Profile

The wheel tread measuring device clamps on the wheel and traces the tread profile onto a sheet of mylar at a one to one ratio.

8.5 TEST PROCEDURE

8.5.1 Lateral Run-out

- jack vehicle;
- install dial indicater;set indicater to "0";
- rotate wheel 30°;
- take and record dial indicator reading;
- repeat 12 times.

8.5.2 Wheel Eccentricity (Vertical)

- jack vehicle;
- install dial indicator;
- set indicater to "0";
- rotate wheel 360°;
- record high and low reading.

8.5.3 Wheel Tread Profile

- install instrument;
- record tread profile.

8.6 METHOD OF ANALYSIS

8.6.1 Lateral Run-Out

Vehicle ride quality and dynamic performance is related to wheel condition and behaviour. It was observed during a demonstration run that the front left wheel would wobble approximately 1/8" left and right from a central point. The vehicle ride seemed to be affected by this wobble. It was concluded that if this apparent wobble could be eliminated by machining the wheel, improved ride quality and wear rate on wheel and rail would result.

8.6.2 Wheel Eccentricity (Vertical)

The method of analysing these measurements is to decide what limits can be set to give an acceptable tolerance without unsatisfactory affecting the ride quality. These limits can then be used to determine if test readings indicate a need for remachining.

8.6.3 Wheel Tread Profile

The method of analysing tread wear is to compare the original profile to the final profile following the mileage accumulation of 3,000 km and determine particular wear patterns (i.e., tread or flange).

8.7 RESULTS

8.7.1 Lateral Wheel Run-Out Measurement

Lateral measurements were taken on 06 September 1985 of both front wheels. These readings indicated a lateral travel of 3.43 mm (.135 in) for the left front wheel and 3.05 mm (.120 in) for the right front wheel. A decision was made at this time to remachine all the wheels to start the test program with wheels that were more true to the axle centreline - see Ref. 3.0 for procedures used.

- Pretest lateral run-out measurements after machining at mileage 0.0 were:

  LF wheel - .64 mm (.025");
  RF wheel - .36 mm (.014");
  LR wheel - .20 mm (.008");
  RR wheel - .69 mm (.027").

- Post test lateral run-out measurements at 3,347 km:

  LF wheel - .23 mm (.0090");
  RF wheel - .50 mm (.0195");
  LR wheel - .22 mm (.0085");
  RR wheel - .79 mm (.0310").

- Pretest eccentricity measurements at mileage 0.0:

  LF wheel - 1.40 mm (.055");
  RF wheel - .64 mm (.025"); -
  LR wheel - .64 mm (.025");
  RR wheel - .53 mm (.021").

- Post test eccentricity measurements at 3,347 km:

  LF wheel - .36 mm (.0140");
  RF wheel - .27 mm (.0105");
  LR wheel - .51 mm (.0200");
  RR wheel - .66 mm (.0260").

8.7.2 Wheel Tread Profiles

Wheel tread profile traces were taken before machining, after machining (at mileage 0.0) and after mileage accumulation of 3,347 km (2,092 mi). Comparison made between the start and end of the test program indicate the four wheels had almost no tread wear.

The two rear wheels showed almost no flange wear however, the front right hand wheel showed a flange wearing at one point near the flange root of about .75 mm (.030 in) and the left hand front wheel had about .25 mm (.010 in) wear in the same general flange area. Review of the following figures indicates the results measured prior to and after the test program:

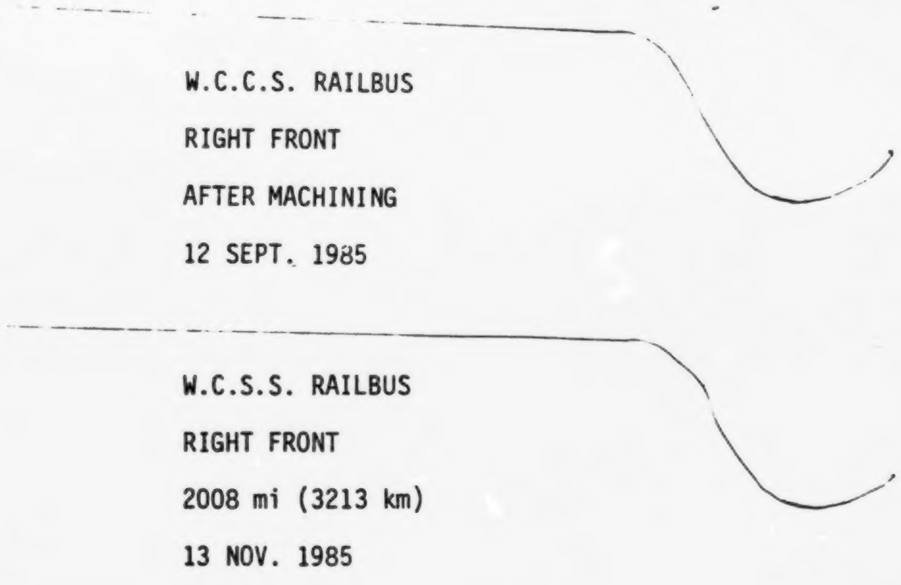

FIGURE 5: COMPARISON OF RIGHT FRONT WHEEL PROFILE BEFORE AND AFTER 3000 KM OPERATION

8.8 CONCLUSIONS

Machining the four wheels to improve the runout and eccentricity improved substantially the ride quality and behaviour of the vehicle particularly at higher rail speeds (up to and including 90 km/h).

Inspection of the wheels indicated no damage and very little wear had occurred on the wheel surfaces following 3,347 km of operational use on the INCO Railway Line.

Inspection of the wheel bearing prior to and after the test program indicated the units to be in good condition and suitable for continued use.

Review of the wheel bearing analysis, using load and acceleration values measured during the test period (see Appendix A), indicates an estimated worst case bearing life expectancy of 1120 hours. The maximum vehicle load configuration of 12,040 kg (26,500 lb) and an average vehicle service speed of 60 kph was used in the analysis. Note that this value derived from test results agrees well with earlier calculations reported in Ref. 2 (1066 hours).

9.0 RERAILING AND WINCH OPERATION

9.1 TEST OBJECTIVE

To demonstrate the suitability of equipment and procedures to be used for the railbus in the event of a derailment.

9.2 TEST APPROACH

It was intended to test the winch, relocated to the rear of the railbus, to enable the vehicle to pull itself back onto the rail surface. Having tested the operation of the winch and determining its rate of drum rotation to be too slow for practical use (about 1 RPM being measured), it was decided to not use the winch at this time and employ an alternate means of rerailing the vehicle.

9.3 INSTRUMENTATION AND EQUIPMENT

Quantity one rail/road crossing, with snow compressed by passing traffic into the rail flangeways. (The crossing used for this test is located within the INCO property on the Southbound line to Pipe Lake Mine).

Quantity one unladen railbus.

9.4 TEST SET-UP

The test was not set up deliberately, it occurred during normal operation and was used as an opportunity to gather data.

9.3 TEST PROCEDURE

The vehicle was driven at steady speed, approximately 15 km/h(10 mph), toward the crossing. The front wheels were observed to leave the track, at which time the service brake applied to arrest forward motion. The vehicle stopped with rear wheels on track, front wheels off track to right (door-side). At this point the flange of the door-side front wheel was approximately 100 mm inboard of the end of the tie on which it rested. The vehicle had travelled 3 m (10 ft) from the point-of-derailment.

The vehicle was then reversed. The driver's-side front wheel was considered to be back on track after 3.5 m (12 ft) of rearward travel, while the door-side front wheel required a further 3 m (10 ft) of travel to climb back into the groove.

9.4 METHOD OF ANALYSIS

Subjective judgement of the Operation Log Book entry, together with comparison of the situation as it existed with that which would be contrived using rerailing ramps.

9.5 RESULTS

The results are recorded in the Operation Log Book, 09 November 1985 at 1441 hours through 1445 hours.

Time required to derail and rerail was 3 minutes.

9.6 CONCLUSIONS

The WCSS Flyer bus modified for use on standard gage railway track has satisfactory rerailing ability in the somewhat benign circumstances recorded.

The winch operation is recommended to be improved to enable its use in a further re-railment demonstration.

10.0 TURNTABLE SYSTEM

10.1 TEST OBJECTIVE

To operate and observe the turntable and hydraulic lift system and verify its reliability and adequacy of design.

10.2 TEST APPROACH

The vehicle lift and turntable system was cycled during the operational test program and observations made of its performance. A determination was made of potential problem areas which would affect its operation during normal and adverse winter conditions. Limited rework of the turntable system would be conducted, if required, prior to the end of the test program.

10.3 INSTRUMENTATION AND EQUIPMENT

The following equipment was used to measure the performance and various components of the turntable system:

- tape measure;
- wheel load-weigh kit (electronic aircraft-type).

10.4 TEST SET-UP

Measurements were taken with the aid of the load-weigh kit of the vehicle's wheel loading to determine the railbus centre of gravity.

Relative to the turntables geometric centre, measurements were taken at the start of the test program following the addition of test equipment and minor modifications made to the vehicle's body. Observation of lift action and performance was noted in the log book during the test program.

10.5 TEST PROCEDURES

The vehicle lift and turntable assembly was cycled during the tests, being conducted on the test track section of the INCO Railway Line. During the completion of each test run on mile 16 to 18, the vehicle was turned 180° and the test was continued. This procedure was repeated several times daily during the two week period prior to the start of the mileage accumulation exercise.

10.6 RESULTS

Following the modification and weighing of the vehicle at the start of the test program, it was determined the turntable's centre was nearly 378 mm (14.8 in) forward of the vehicle's centre of gravity. It was concluded the weight added to the vehicle during it's preparation for testing contributed partially to the situation, however, even without the modifications the turntable was still incorrectly located. It should be noted that all measurements were taken with a full tank of fuel.

The vehicle's lift system was observed to raise the front axle completely before the rear axle would leave the track. Wheel lift on both axles was unequal during its operation. This caused considerable stress in the hydraulic rods attached to the turntable. The hydraulic cylinders failed (three of four rods) after approximately 30 vehicle lifts. These failures occurred at the rod attachment point to the turntable. Observation concluded the lift system was required to be relocated under the vehicle's centre of weight, structural components inspected and repaired, and the hydraulic cylinders to be upgraded and replaced with larger diameter rods.

Modifications did not occur till near the end of the test program and following the accumulation of the required 3,000 km of operational track experience. The turntable was locked into its retracted position during the mileage accumulation tests and the "wye" used at each end of the railway line for turning of the WCSS railbus.

The turntable was modified by relocating its centre to coincide with the vehicle's centre - 2,820 mm forward of the rear axle. The four hydraulic lift cylinders where each upgraded with 50 mm rods, structural components repaired and stiffener brackets added to the guide assembly. Operation of the vehicle lift following the improvements resulted in an equal lift behavior - during normal air temperatures (+10°C). Operation during cold winter conditions (-35°C) still resulted in an unpredictable wheel lift behavior and was concluded to be the result of the hydraulic circuit design and its component selection.

10.7 CONCLUSION

In its present form, the turntable system is not suitable for a reliable service demonstration of the railbus on the CN Railway Line. The hydraulic circuit and control features used for the operation of the vehicle lift require further assessment and improvement.

It is recommended the following to be considered as further modifications to the turntable:

- The hydraulic flow dividers (3) to be replaced with temperature and pressure compensating flow control valves (4);

- The hydraulic fluid type to be replaced with an arctic-type grade;

- The control valves to be relocated into an easily accessible area and made adjustable in the field; and

- The turntable system be further cycled in extreme winter conditions to assess its reliability prior to vehicle operation on the CN Railway Line.

11.0 ENERGY

11.1 TEST OBJECTIVE

To evaluate the energy requirements for the railbus during an emergency service demonstration (Engine Disabled).

11.2 TEST APPROACH

The emergency services required was determined to include marker lights, driver's dome light and auxiliary heater. The energy required to support these services would be evaluated with the engine shut-off.

11.3 INSTRUMENTATION AND EQUIPMENT

The following equipment was used to measure the performance of the vehicle's energy requirements:

- o hydrometer, commercial quality, without temperature compensation;
- o digital voltmeter, Fluke 8000A, calibrated and certified by UTDC Instrument Laboratory;
- o DC ammeter, clamp-on type, Kyoritsu KEW Snap-7; and
- o stopwatch.

On site calibration was confined to the clamp-on DC ammeter. The operating principle of this instrument renders it susceptible to the effect of stray magnetic field. Calibration consisted of ensuring that needle deflection of the installed meter was zero when the current in the circuit-under-test was known to be zero, i.e., when the circuit was disconnected.

11.4 TEST SET-UP

The tests were conducted with the engine off and all circuit breakers and switches were open.

The battery temperature was estimated to be 20°C (68°F).

11.5 TEST PROCEDURES

During the twelve (12) days prior to the tests the starter motor field windings had shorted to ground and the alternator drive belt had been found to be slipping due to insufficient tension. The troubleshooting, corrective and monitoring activity ensuing from this resulted in frequent measurements of battery terminal voltage, under various loads, and electrolyte specific gravity. From these measurement it was determined that, while the battery was not in "as new" condition, much useful service life remained. It was deemed representative, therefore, of actual service conditions, to carry out the tests without further measurements of battery terminal voltage or specific gravity.

- o Battery switch (also know^as "main switch" and as "master switch") was closed.

- o The unmarked 3-position toggle switch on the driver's dash panel was set to the 'left'. Current in each of the green rear-mounted marker lamps was measured and noted.

- o The unmarked 3-position toggle switch on the driver's dash panel was set to the 'right'. Current in each of the red rear-mounted market lamps was measured and noted.

- o The unmarked 3-position toggle switch on the driver's dash panel was set to the 'centre' (off) position.

- o The key-controlled switch also known as "ignition switch" on the driver's dash panel was closed. Current in each of the white forward-mounted classification lamps was measured and noted.

- o The key-controlled switch was opened.

- o The ammeter was clamped around the cable between battery and battery switch.

- o Using the rotary switch on the driver's dash panel, the auxiliary heater was switched on. The green indicator lamp in the switch was observed to light and simultaneously the stopwatch was started. The ammeter indication was noted. After a period of time the current stepped to a lower value at which instant the stopwatch was stopped. The time and the new value for current were noted.

- o The auxiliary heater was switched off.

- o The "Driver's Dome Light" was removed, inspected, found to be identified as bulb type 1156 and re-installed.

- o The "Driver's Dome Light" pull switch on the driver's dash panel was closed and the driver's dome light was observed to light. The auxiliary heater and one pair of marker lamps (at the rear) were switched on. After a period of time the current was observed to step to a lower value, which was noted. The two marker lamps were observed to be lit and warmed air issued from the auxiliary heater register.

- o The auxiliary heater, the driver's dome light and the marker lamps were switched off.

- o The key-controlled switch was closed and it was observed that various devices operated including, but not necessarily confined to, the following:

  - Mobile telephone (Bell equipment)
  - Fuel pump
  - Instruments (gauges)
  - Divers driver's indicator (air, oil, step, etc.)
  - White classification lights (front)

  N.B. It is known that, in this mode, certain engine control solenoids are energized.

- o The battery current required for the services was observed to be almost three (3) times the current required by the two white classification lights alone.

- o The key-controlled switch was opened.

- o The battery was examined and, based on physical size, capacity was estimated.

11.6 METHOD OF ANALYSIS

11.6.1 Description

The total current drawn by the identified emergency services was measured directly.

11.6.2 Definitions

- Marker lights are the colored (red, green) lights mounted on the back of the railbus.
- Classification lights are the white lights mounted at roofline on the front of the railbus.

11.7 RESULTS

Test data was entered in the Operational Logbook and is summarized by the following:

DEVICE/SYSTEM	CURRENT
Each marker light	0.6 A
Each classification light	3.0 A
Auxiliary heater, for first 60 sec.	21.0 A
Auxiliary heater, after first 60 sec.	6.5 A
One pair marker lights, + Driver's dome light + Auxiliary heater, after first 60 sec.	9.5 A
Keyswitch closed, other equipment off	16.0 A

The battery appears to be a group-4 component, in serviceable condition, the 20-hour rate of which can reasonably be expected to exceed 10A.

11.8 CONCLUSIONS AND RECOMMENDATIONS

The WCSS Flyer modified for use on standard gauge railway is equipped with a battery which, if properly maintained, is capable of operating the identified emergency services for a period of at least 20 hours.

The communication device, i.e., the mobile telephone, and light of any kind at the front of the bus are not at present identified as required emergency services.

Operation of the mobile telephone in standby mode requires that the keyswitch be closed, thus energizing systems which are not required. The same is true of the front classification lights.

It is recommended that the emergency external lighting should be reviewed with the objective of providing a warning light at least to both front and rear with no increase in current drain. A single roof-mounted strobe may be satisfactory. Also, it is recommended that:

- All controls should be clearly marked; and
- All emergency procedures should be clearly defined in the Operator's Manual.

12.0 DRAW-BAR OPERATION

12.1 TEST OBJECTIVE

The draw-bar was to be tested to demonstrate its safe and reliable operation during a vehicle recovery demonstration.

12.2 TEST APPROACH

The draw-bar attachment was to be utilized on each end of the Railbus and the vehicle towed/pushed at various speeds through several track curves and tangent sections.

12.3 INSTRUMENTATION AND EQUIPMENT

The draw-bar equipment consisted of:

- a modified "E" type AAR coupler knuckle;
- a knuckle adaptor; and
- a draw-bar and extension.

12.4 TEST SET-UP

The test was set-up using an INCO yard engine as the tow vehicle and connecting the motive unit to the Railbus by the draw-bar assembly. The test site was located at the INCO yard where track curves to the left and right were approximately 9°.

12.5 TEST PROCEDURE

The test was carried out in the following sequence:

- yard engine was connected to front of bus with tow bar assembly;

- bus was pushed through right hand curve at about 20 km/h;
- bus was pulled through same curve at about 20 km/h;
- bus was pushed through left hand curve at about 20 km/h;
- bus was pulled through same curve at about 20 km/h;
- bus was disconnected from yard engine, turned, and the rear of the bus was connected through the tow bar assembly to the yard engine;
- bus was pushed through right hand curve at about 20 km/h;
- bus was pulled through same curve at about 20 km/h;
- bus was pushed through left hand curve at about 20 km/h; and
- bus was pulled through same curve at about 20 km/h;

12.6 METHOD OF ANALYSIS

The method of analysis for this test was observing draw-bar operation during both push and pull modes.

12.7 RESULTS

Results of the test on 09 October 1985 at the vehicle unladen weight was satisfactory. Because of design of draw-bar (3 pivot points) yard engine coupler moved to one side during push mode. This did not appear to have any adverse affect on the performance of the draw-bar assembly.

12.8 CONCLUSION AND RECOMMENDATION

The operation of the drawbar attachement proved satisfactory for both push and pull modes of vehicle recovery.

It is also recommended that an alternate drawbar attachment be fabricated which is lighter in weight and design and would allow improved connection geometry with the mating motive power unit.

13.0 DEADMAN SWITCH AND BRAKES

13.1 TEST OBJECTIVE

To test the operation and performance of the deadman switch and braking system during trial emergency vehicle stops.

13.2 TEST APPROACH

The deadman switch is designed to operate with the service brakes in order to bring the vehicle to an emergency stop when the operator is incapacitated. Testing the foot-activated switch was carried out by releasing the switch at various rail speeds and measuring the elapsed time from release to vehicle standstill.

13.3 INSTRUMENTATION AND EQUIPMENT

The time required for the railbus to come to rest during the test trials was measured with a handheld stopwatch.

13.4 TEST SET-UP

The foot-activated switch was mounted to the cab floor near the left side of the driver's seat. Air and electric control solenoids, designed to limit the engine speed, were installed onto brackets mounted to the fuel injector pump and adjusted for the desired operation.

When released, the foot-activated switch would engage the control circuit whereby the engine speed is reduced to its low idle (600 RPM). At this RPM, the automatic transmission is reportedly incapable of driving the rear-driven axle. The air activated wheel mounted service brakes are simultaneously gradually applied up to a maximum active pressure of 275 kpa (40 psi). The resultant combination of lowering the engine speed and application of the service brakes enables the vehicle to come to an emergency stop. The distance travelled and time required for the vehicle to come to rest from various track speeds were to be determined.

13.5 TEST PROCEDURE

The vehicle was driven to the test site (mile 16 to 18) of the INCO Railway Line. From its rest position and with deadman switch depressed, the vehicle was accelerated to a predetermined cruise speed (32 km/h). Once the cruise speed was reached and maintained for a short duration (5-10 seconds), the deadman switch was released. The time was measured for the railbus to come to rest as well as observations made of vehicle behaviour and performance (wheel skid, sudden deceleration rate, etc).

The procedure was repeated for various cruise speeds and for either direction of travel.

13.6 RESULTS

During tests conducted on the INCO track, the deadman control functioned adequately with a comfortable deceleration rate being observed for the railbus (approximately 1.1 m/s^2) (See Table 13 for results).

Wheel skid on the dry track was not observed during any of the trial tests for any of the speed tests conducted. Brake-drum temperatures were also determined to be acceptable for the tests conducted (hand-felt).

The service brakes were tested for the number of applications possible with the engine shut-off. Approximately 15 applications were possible with the existing size of air reservoirs (2) before brake-line pressure available was reduced to below 275 kPa (40 psi).

Vehicle Cruise Speed (km/h)	Time to Stop (second)	Distance* to Stop (meters)
32	8	35
48	12	80
64	15	133

TABLE 13: DEADMAN SWITCH BRAKING RESULTS

*Note: Calculated from stopping times

13.7 CONCLUSIONS

The deadman control circuit was determined to be suitable in operation and performance for the demonstration tests to be conducted on the CN Rail Line.

It is noted however, given the present circuit layout for the control system, that if the accelerator pedal is depressed and held firmly in position for rail speeds over 60 km/h, the railbus would not come to a complete stop. This will be corrected prior to the railbus operation on CN Line.

14.0 EMERGENCY ENGINE AND POWER SHUT-OFF SWITCH

14.1 TEST OBJECTIVE

To verify the operation and adequacy of the engine and power shut-off switch during simulated emergency stops.

14.2 TEST APPROACH

The emergency power shut-off switch is designed to allow the operator to quickly shutdown the engine and electrical power system, if required. Testing of the device was to be carried out by tripping the device at different engine RPM's and measuring the elapsed time to engine standstill.

14.3 INSTRUMENTATION AND EQUIPMENT

The following equipment was to be used to measure the performance of the emergency system:

- handheld stop watch; and
- DC ammeter, clamp-on type, KYOR17SU KEW Snap-7.

14.4 TEST SET-UP

An emergency electrical power shut-off switch had been mounted to the cab wall, adjacent and easily accessible to the operators left hand. The switch circuit was arranged to enable the operator to disconnect the battery's "negative" terminal from the bus body when moved (rotated) to its shut-off position. The ammeter was clamped to the battery's negative cable.

The vehicle was also equipped with an electrically operated key shut-off switch for the engine.

Tests were to be conducted for the vehicle in its unladen position and performed within the switch yard outside the INCO maintenance facilities.

14.5 TEST PROCEDURE

With the engine started and idled (600 rpm), the emergency power shut-off switch was activated and observations recorded in the operational log book. The procedure was repeated at various engine RPM's.

14.6 RESULTS

Activation of the emergency power switch into its shut-off position resulted in the disruption of the battery's electrical power from the vehicle's auxiliary circuits. The ammeter indicated that no current was being taken from the battery. However, the engine was not disabled and continued to operate as normal. The engine was disabled with the ignition key turned to its "Off" position.

When the test was repeated at higher engine RPM's, the same observations were recorded for engine behaviour and electrical power measurements.

14.7 CONCLUSIONS AND RECOMMENDATIONS

The emergency power shut-off switch operates satisfactorily in disconnecting the auxiliary electrical circuits from the battery, however, does not disable the operation of the engine. It is recommended that operation of the emergency power switch be modified to include disabling of the engine, or as an alternative, to provide a mechanical engine shut-off feature (pull-cable) which would be easily accessible to the operator.

15.0 MILEAGE ACCUMULATION

15.1 TEST OBJECTIVE

To accumulate 3000 km of operational experience while in test service on the INCO Railway Line.

15.2 TEST APPROACH

Measurements of the number of wheel rotations were taken during daily inspection and operation of the railbus. The mileage accumulation commenced at the start of the test period and accumulated during regular trips being made on the railway line. The test was scheduled to be completed within 60 days of the start of the program.

15.3 INSTRUMENTATION AND EQUIPMENT

Wheel rotations were measured and recorded from a mechanical-type revolution counter ("Hubodometer") mounted onto the front left-hand wheel (undriven). The hubodometer was insensitive to the direction of wheel rotation.

15.4 TEST SET-UP

The wheel's inner hub was first modified by drilling and tapping a hole on the centreline. The hubodometer was threaded into the hole and locked into place.

15.5 TEST PROCEDURE

The hubodometer reading was taken at the start of the test program and checked daily during the routine inspection of the vehicle. The readings were recorded in the log book which was kept at all times with the railbus. Periodic assessments of the distance accumulated was made during the course of the test.

15.6 METHOD OF ANALYSIS

The determination of the mileage accumulated was as follows:

$$\text{Distance Travelled} = \left[\text{Hub}_F - \text{Hub}_S \right] . \frac{C_{1R}}{1.0 \times 10^5} \qquad \ldots.(\text{km})$$

where: Hub_F = Final Hubodometer reading
Hub_S = Initial Hubodometer reading
C_{1R} = Wheel Circumference (mm)
= 2872 mm

15.7 RESULTS

The measurements taken of the hubodometer before and after the test period were as follows:

Date	Hubodometer Reading
12 September 1985	0013130 (start)
18 November 1985	0129673 (final)
TOTAL:	116543

The distance travelled was determined as:

$$\text{Distance} = 116543 \;.\; \frac{2872}{1.0 \times 10^5}$$

$$= \underline{\underline{3347}} \text{ km}$$

15.8 CONCLUSION

During the course of the test program conducted on the INCO Railway Line, the WCSS Railbus accumulated 3347 km of operational track experience.

16.0 SUMMARY OF RESULTS

The WCSS Railbus was demonstrated during several weeks of operational test trials conducted on the INCO Railway Line.

A summary of observations made on the design of the vehicle are as follows:

Vehicle Noise - Following the addition of sound dead materials to the engine area and improvements in drive-line design (vibrations), the interior noise levels measured at the operator's location was judged as "acceptable" (85-87 dB(A) at 72 km/h).

Vehicle Vibrations - Lateral and vertical accelerations of the vehicle's axles during normal operation were observed to be "very acceptable" and substantially lower than initially predicted - average dynamic axle accelerations for the fully laden vehicle were measured at 0.9 G, with peaks to 4.2 G, for the vertical and 0.5 G, with peaks at 1.5 G, for the lateral rate.

Ride Quality - Measurements of ride quality for both laden and unladen vehicle configurations were recorded on a British Ride meter. The Railbus was tested at an operational speed of 72 km/h. An average BR Number of 3.6 was measured for the vertical ride, which corresponds to a "just satisfactory" quality of ride. An average BR Number of 3.8 "operable", was measured for the lateral ride over the front axle falling to a value of 3.0, "satisfactory", at the mid and rear position. In general, the ride quality for the WCSS Railbus is considered as "just satisfactory".

Wheel/Rail Interference - In consideration of the vehicle's stability, curving behaviour and switching behaviour as observed and recorded on body mounted video cameras, the

Railbus was judged as "very acceptable" for operational service at all rail speeds, up to and including 90 km/h.

Fuel Consumption - Based on several representative service runs, the WCSS Railbus in typical operation is likely to consume fuel (diesel) at an average rate of 5.43 km/L (15 mpg).

Reliability and Wear - The wear observed and measured on the wheel bearings and wheel running surfaces after over 3347 km of operational use was judged as "very acceptable". The highest wheel profile wear (.75 mm) was measured on the front right-hand wheel surface, at the flange radius. Some minor wheel "flats" were observed on all wheels (from slide braking) however were judged as not being a serious problem.

Rerailing and Winch Operation - The design displacement of the hydraulic pump and motor utilized to drive the winch was judged as "unacceptable" - the winch would rotate at a maximum rate of only 1 RPM. As a result, a suitable rerailment test using the winch could not be demonstrated and had to be postponed till the operation of the device was improved. It is noted however, the WCSS Railbus had sufficient drive-axle traction (without sanders) in order to back itself onto the track when the vehicle front wheels derailed at a snow-packed road crossing.

Turntable System - The hydraulic lift cylinders failed during the early part of the test program after nearly 50 vehicle lifts were performed. Primarily attributed to the mismatch of the turntables lift-centre relative to the vehicle's centre-of-gravity, the vehicle has been recently modified to correct the problem and upgrade the turntable's capabilities. However, erratic lift behaviour in cold weather conditions has continued to plague the reliability and operation of the system. The system's design has been judged as "unsatisfactory" for continued use in its present configuration.

Energy - Load Current measurements taken from the battery during a simulated emergency service demonstrations (i.e. engine off, emergency heater on, some interior lighting on) indicated the battery life could "satisfactorily" sustain the vehicle's occupants during an emergency. The auxiliary or emergency heater, however, had an "inadequate" heat output in cold weather conditions and requires improvements in its operation.

Draw-Bar Operation - Tests whereby the Railbus was pushed and pulled at either end using a motive power unit and tow-bar attachment indicated the design and operation were "satisfactory".

Deadman Switch and Brakes - The design and installation of the device for stopping the Railbus during an emergency was judged as "satisfactory". The vehicle's deceleration rate during its stop was measured at approximately 1.1 m/s^2.

Emergency Engine and Power Shut-Off Switch - Operation of the master power switch was determined as being "satisfactory" for disconnecting the auxiliary electrical circuits from the battery, however, the switch was unable to simultaneously disable the engine's operation. Given an emergency, it is suggested an alternate mechanical means be adapted to quickly and reliably shut-off the engine's power.

Mileage Accumulation - During the course of the test trials, the WCSS Railbus had accumulated 3347 km of operational track experience.

17.0 RECOMMENDATIONS

Review of the test results has led to the following recommendations for vehicle improvements:

- The operation of the rerailment winch to be reviewed and the appropriate sizes (displacement) of hydraulic components installed;
- The reliability of the turntable system to be improved, particularly the hydraulic circuit, in order to regulate and accurately proportion the flow to the lift cylinders;
- The design and operation of the emergency heater to be reviewed and its thermal output to be upgraded for use during cold weather conditions;
- The operation of the deadman switch to be modified to prevent the operator from over-riding its action; and
- A fail-safe, mechanically operated control (pull-cable) to be installed at the engine to enable the operator to quickly and effectively disable the engine during an emergency.

18.0 REFERENCES

1. "Test Plan For Testing Of WCSS Railbus On INCO Railway Line", TTL Report No. 338-610-001, August 1985.

2. "WCSS Railbus - Vehicle Inspection and Assessment", TTL Report No. 338-620-002, November 1985.

3. "WCSS Railbus - Vehicle Preparation", TTL Report No. 338-620-001, November 1985.

4. "WCSS Railbus - Vehicle Modifications," TTL Report No. 338-640-002, November 1985.

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Project Railbus	**Title** Test Report Appendix A - Wheel Bearings Calculations	**Report No** 338-610-002		
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		By H.R.S.	**Appd**	

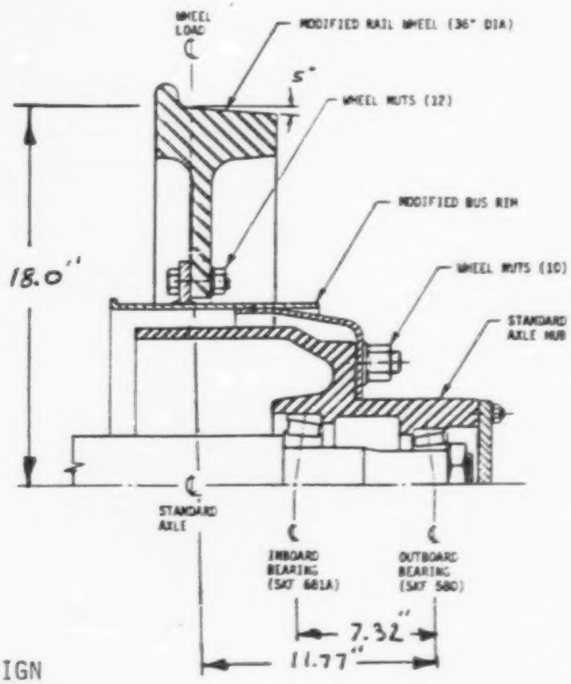
APPENDIX A

WHEEL BEARING CALCULATIONS

o The following analysis was carried out using results obtained from various test reports included in TTL Report No. 338-610-002, "Evaluation Testing on INCO Railway Line".

o Bearing design data and life calculations were obtained from an SKF Engineering manual.

1.0 WHEEL DESIGN


WHEEL LOAD ℄
MODIFIED RAIL WHEEL (36" DIA)
5°
WHEEL NUTS (12)
MODIFIED BUS RIM
WHEEL NUTS (10)
STANDARD AXLE HUB
18.0"
℄ STANDARD AXLE
℄ INBOARD BEARING (SKF 681A)
℄ OUTBOARD BEARING (SKF 580)
7.32"
11.77"

2.0 BEARING DESIGN

a) Location: Inner Bearing

Type : 681A

d = 3.625 in
D = 6.625 in
T = 1.625 in

Load Rating: Dynamic (C) = 45,200 lbs
Static (Co) = 40,500 lbs
Axle Load Factor (Y) = 1.25

b) Location: Outer Bearing

Type: 580

$d = 3.250$ in
$D = 5.5115$ in
$T = 1.4375$ in

Load Rating: Dynamic (C) = 37,100 lbs
Static (Co) = 32,100 lbs
Axle Load Factor (Y) = 1.50

3.0 WHEEL LOADS

Location	Vehicle Unloaded (lbs)	Vehicle Loaded (lbs)
Front R.H. Wheel	4,528	5,226
Front L.H. Wheel	5,594	6,222
Rear R.H. Wheel	6,452	7,708
Rear L.H. Wheel	6,083	7,340
Total	22,730 lbs	26,500 lbs

4.0 STATIC WHEEL LOADS (FWS)

- o Assume the worst case for wheel loading will be typical for bearing load in static condition, that is:

Wheel Load at Rail - 7708 lb
Less Wheel Weight - 450 lb (estimated)

Thus, radial static load on bearing 7258 lb

i.e. $F_{WR} = 7528$ lb

Axial static load on bearing 0 lb (approximate)

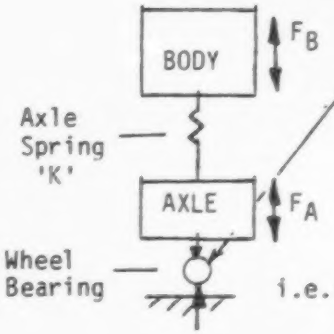
i.e. $F_{WA} = 0$ lb

5.0 DYNAMIC WHEEL LOADS (F_{WD})

- The following values were approximated for the mass of vehicle components over each wheel bearing assembly:

Body (M_B).........6783 lb
Axle Spring (M_A)...475 lb

(Note: Body + Axle and Spring = Bearing load)



Assume wheel bearing, hub, rim, and rail are rigid to ground.

Thus, dynamic radial load on wheel bearing is the result of dynamic motion of body and axle relative to the stationary wheel bearing.

i.e.: $$F_{WD} = F_{WS} + F_B + F_A$$
$$= F_{WS} + M_B A_B + M_A A_A$$

Where: F_{WS} = Static Wheel Load
M_B = Body Mass (6789 lb)
M_A = Axle & Spring Mass (475 lb)
A_B = Body Acceleration
A_A = Axle Acceleration

- Results of actual test measurements are summarized in the following table:

Note:

- Axle acceleration rates were actual values measured while body acceleration rates were determined from British Ride Meter measurements (fully laden, front-axle); and

- Review of test measurements indicated an amplitude frequency of 3.8 Hz for the average ride index and 0.5 Hz for the peak index.

LOCATION	DIRECTION	ACCELERATION ('G') AVERAGE	PEAK
BODY	LATERAL VERTICAL	.85 (3.8)* .070 (3.3)*	.20 (4.0)* .18 (3.6)*
AXLE	LATERAL VERTICAL	.50 .90	1.50 4.20

* British Rail Measurements

- Assume body and axle motions are in phase and act as one force on wheel bearing (i.e. $F_{WD} = F_{WS} + F_B + F_A$)

- Assume in the lateral direction, due to flanging, normal vehicle motion is guided by the wheel flanges on one side only (i.e., in the lateral direction

$$F_{WD} = 2\ (F_B + F_A)/10$$

- Thus, in consideration of component masses of the body and axle assembly and the acceleration rates measured (G), the dynamic forces (F_{WD}) acting on the bearings has been approximated in the following table:

FORCE DIRECTION	CONDITION	WHEEL LOADS F_{WS} (lb)	F_{WD} (lb)
LATERAL	AVERAGE PEAK	0 0	160 415
VERTICAL	AVERAGE PEAK	7,528 7,528	8,430 10,740

- A review of test measurements suggests the peak bearing loads occur, in the worste case, at approximately 20% of a given time internal.

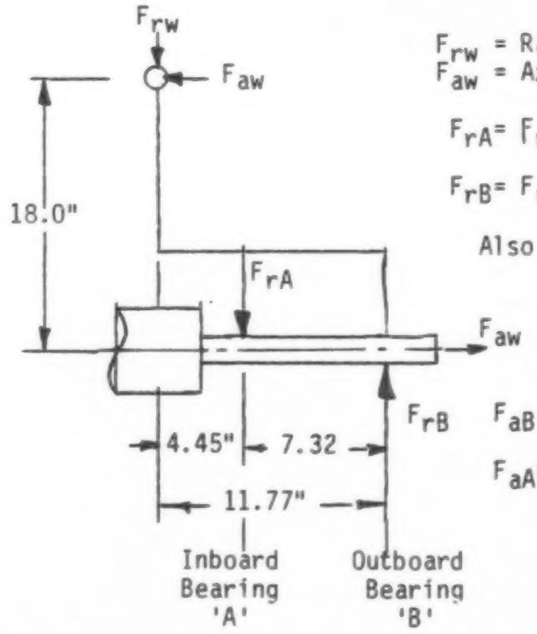
- A mean dynamic load can be approximated as:

$$F_{mean} = \frac{1}{0.2/F_{max} + 0.8/F_{av}}$$

- The corrected value of mean dynamic loads (F_{WD}) used in the bearing calculations is as follows:

Force Direction	F_{WS}	F_{WD}
Lateral (F_{aw})	0 lb	185 lb
Vertical (F_{rw})	7,528 lb	8,800 lb

- BEARING LOADS CALCULATIONS



F_{rw} = Radial Load at Wheel
F_{aw} = Axial Load at Wheel

$$F_{rA} = F_{rw}\frac{(11.77)}{7.32} + F_{aw}(18.0)$$

$$F_{rB} = F_{rA} - F_{rw}$$

Also $Y_A = 1.25$
$Y_B = 1.50$

$$F_{aB} = 0.5(F_{rB})/Y_B$$

$$F_{aA} = F_{aB} + F_{aw}$$

BEARING LOAD RATINGS

DYNAMIC BEARING LOAD: $P = 0.4\ Fr + Y\ Fa$ $\quad P(min) = F_r$

STATIC BEARING LOAD: $Po = 0.5\ Fr + Yo\ Fao$ $\quad Po(min) = F_r$

For Inner Bearing "A" in loaded case with Fa = 0

Dynamic Load Pa = 17,500 lb $\quad C = 45,200$ lb
Static Load Poa = 12,104 lb $\quad C_0 = 40,500$ lb

For Outer Bearing "B" in loaded case with Fa = 0

Dynamic Load Pa = 8,680 lb $\quad C = 37,100$ lb
Static Load Poa = 4,576 lb $\quad C_0 = 32,100$ lb

Therefore comparing load ratings C and Co for both bearings, design appears to be acceptable.

- o When comparing for continuous duty at loaded configuration and shock loads continuously on wheels:

  $Po^1 = So\ Po$ vs Co
  Where So = Factor of safety = 2.5
  Thus for bearing 'A'
  $Po^1 = (2.5)(17,500)$
  $= 43,700$ lb
  Co = 40,500 lbs.

- o From this it would appear bearing A would not be suitable, however this scenario would not be likely.

Life Equation:

o The basic rating life equation is expressed as:

$$L_{10} = \left[\frac{C}{P}\right]^{p}$$

Where: L_{10} = life in millions of revolutions

C = basic dynamic load rating, N

P = Equivalent dynamic load, N

p = exponent for life equation

= 10/3 for roller bearings

o Assume vehicle will be operating at a constant speed, thus

$$L_{10h} = \frac{1,000,000}{60(n)}\left[\frac{C}{P}\right]^{p}$$

Where: L_{10h} = basic life in operating hours

n = rotational speed, RPM

o Assume average vehicle speed (V) is 60 kph (37.5 mph):

$$\text{Rotational speed } (n) = \frac{V \times 5280}{60 \times \pi\ (D/12)}$$

Where: D = measured wheel dia.

= 35.8 in

Therefore n = 352 rpm

Therefore, $\boxed{L_{10h} = 47.3\left[\frac{C}{P}\right]^{p}}$ hours for inner bearing 'A', for worst case:

$$L_{10h} = 47.3 \left[\frac{Ca}{Pa}\right]^{p}$$

Where: $C_a = 45{,}200$ lb

$Pa = 17{,}500$ lb

$p = 10/3$

Therefore L_{10h} ÷ 1,120 hours

For outer bearing 'B', for worst case:

L_{10h} ÷ 6,000 hours